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SAMUEL PIERPONT LANGLEY

By C. G. ABBOT

Samuel Pierpont Langley achieved distinction as one of the earliest and foremost of the students of astrophysics, but in his later life added to his great and world-wide reputation by a service of over eighteen years as secretary of the Smithsonian Institution, during which he conducted his remarkable experiments in aërial navigation, and founded and directed the Smithsonian Astrophysical Observatory. Born in Roxbury, Mass., August 22, 1834, he was graduated from the Boston High School in 1851, and took up the study of civil engineering and architecture, which professions he subsequently practiced until he had laid by what was for those times a fair competency. During the years 1864 and 1865 he traveled extensively in Europe, and visited the principal observatories and learned societies there. During this time he formed the purpose of devoting the remainder of his life to scientific pursuits, and primarily to astronomical investigations, for he had been from childhood eagerly interested in astronomy. Returning from Europe, he was appointed assistant at the Harvard College Observatory in 1865, and assistant professor of mathematics in the United States Naval Academy in 1866. While at Annapolis he reorganized the small observatory there. In the same year he became director of the Allegheny Observatory, and professor of astronomy and physics in the Western University of Pennsylvania, where he remained

twenty years. In 1887 he was appointed first assistant secretary of the Smithsonian Institution, and later in the same year, after the death of Secretary Baird, he was elected secretary of the Smithsonian Institution, which high position he retained until his death, February 27, 1906.

As secretary, he brought the Smithsonian Institution more prominently before the notice of the foreign public than had either of his predecessors. This was due in part to his great personal reputation as an astronomer, fully established abroad before his accession to the secretaryship; to his far-famed experiments on aërial flight made during his incumbency; to his frequent journeys abroad in the interests of the Institution; to his careful attention to the systems of publication and international exchanges of scientific publications and specimens; and to his broad administration of great bequests, like the Hodgkins Fund for the promotion of investigations concerning the atmospheric air. During his administration the funds controlled by the Institution were largely increased. He will be remembered as the founder of the Smithsonian Astrophysical Observatory and of the National Zoölogical Park. His interests were extremely broad, including, besides the lines of scientific work in which he became renowned, the love of art, of literature, of antiquities, and especially of the young. One of his later official acts was to provide a room of the Institution, beautifully lighted and decorated, including the choicest of remarkable specimens from the collections of the Institution and National Museum, labeled interestingly in plain English, for arousing the interest and delight of children; and this he called "The Children's Room."

Mr. Langley felt that he was risking a well-earned and valued reputation, when he undertook his researches in aërial navigation. The subject had long been principally given over to cranks, and was more likely to bring ridicule than reward to any serious investigator who might study it. But the flight of the soaring birds had been an enticing mystery to him from the days when, as a boy, he lay upon his back and watched their beautiful evolutions and wondered how they could accomplish them; and Mr. Langley determined to use his skill, his influence, and his reputation in an attempt to solve the mystery of soaring flight. His two papers,

"Experiments in Aërodynamics" (1891) and "The Internal Work of the Wind" (1893), created a profound impression, and have done very much to put the problem of flight on a sound experimental basis. Basing his work on the foundation he had thus laid, Mr. Langley succeeded in 1896 in designing and flying a large model of a machine which he called an "aërodrome," heavier than the air, and sustained like a bird by wings. But as he was several years in advance of the present wide application of the gasoline motor, his success then was only possible after he had, with infinite perseverance, obtained a steam engine weighing but five pounds to the horse-power. From this time to 1903, successful flights of large aërodrome models were repeatedly made under his direction, and, at the request of the Bureau of Ordnance and Fortification of the War Department, he superintended the construction, under the immediate charge of Mr. C. M. Manly, of an aërodrome designed to carry a man, and driven by a powerful gasoline motor. In two trials of this machine made on the Potomac River in the autumn and winter of 1903, the experiments were foiled in each instance by accidents during the act of launching, so that the capacity of the device for free flight was never put to test. Fortunately no loss of life occurred in these trials, and the machine was in neither case permanently injured, but a combination of untoward circumstances, including failing health, dissuaded Mr. Langley from continuing the experiments, though it was the firm belief of those best able to judge that success was within reach.

As an astronomer Mr. Langley was from the first interested chiefly in the most original of investigations relating to the physical nature and functions of the celestial bodies, rather than in measurements of time, distance, and position. But during the whole period when he was director of the Allegheny Observatory the funds available to him for research scarcely amounted to $5,000 a year, and were chiefly gained by his own efforts in enlisting the co-operation of friends, and by another measure which shows his genius for adapting means to an end. Among the first steps which he took as director was to offer to supply from the Allegheny Observatory accurate time to all the lines under the control of the Pennsylvania Railroad. This offer was accepted, and marks the first considerable trial in

this country of the now universal practice of furnishing uniform time-service to railroads. The compensation for this service was one of the chief sources of support to Mr. Langley's work during the whole time that he was at Allegheny.

As an observer at the eye-end of an equatorial it is doubtful if there was ever Mr. Langley's superior. His visual studies of the minute structure of the Sun's surface have long been classical. His capacity for seeing and delineating what he saw was so full and exact that his sun-spot drawings made at Allegheny prior to 1875 are even yet regarded as the best recorded evidence of the structure of sun-spots. The present writer has indeed been repeatedly assured by Professor G. E. Hale, who has enjoyed the choicest opportunities for examining the Sun, both with the 40-inch refractor of the Yerkes Observatory and with the horizontal telescope on Mount Wilson, and also during various expeditions to high mountain peaks, that in the best views of sun-spots he has ever had, the better they were seen, the more nearly have they appeared as shown in Langley's drawings.

Mr. Langley observed the total solar eclipses of 1869, 1870, 1878, and 1900, and his account of his observations of 1878 from the summit of Pike's Peak is particularly notable. His visual observations of the solar spectrum, made before the days of Rowland's great contribution to spectroscopy, are even yet favorably referred to, notwithstanding the immense advantages which present day observers have in the Rowland gratings, and the use of photography.

But Mr. Langley's distinction as a visual observer pales before his great contributions to the study of radiation by electrical thermometry. As early as 1870 he began to study the radiation of the Sun by heat methods. He made careful investigations of the relative intensity of radiation from different parts of the Sun's disk, including sun-spots. In these studies he employed the thermopile, but he became more and more dissatisfied with this instrument, on account of its slowness of response and the inadequacy of its sensitiveness to the measurements which he desired to make. His experiments with this instrument on the solar spectrum convinced him that something as much superior to the thermopile of those

days as that was to the thermometer would be required before any satisfactory progress in this direction would be possible. From 1878 to 1880 he was engaged in various attempts to devise a more perfect instrument for measuring radiation, and succeeded at length in the invention of the bolometer, an instrument now in world-wide use. With this new instrument, essentially an electrical thermometer on the principle of Wheatstone's bridge, he proceeded at once to explore the spectrum of the Sun; extended it and mapped it in regions before almost unsuspected, beyond the red; studied the action of the Earth's atmosphere in selectively scattering and absorbing the solar rays of all wave-lengths; estimated the solar constant of radiation by a new method, making for this purpose an expedition to a high mountain 3,000 miles distant from Allegheny; determined the connection between temperature and distribution of radiation in the spectrum of heated terrestrial substances; and studied the spectrum and estimated the temperature of the Moon. All these epoch-making investigations he directed, published, and largely performed with his own hands, in the years between 1880 and 1888.

Mr. Langley's investigations in radiation fall readily into several distinct groups as follows:

(1) The distribution of radiation over the surface of the Sun, and in sun-spots.

He began these studies about 1870, and published repeatedly on the subject until 1877, giving the results of measures with the thermopile on different parts of a large solar image. The rate of diminution of brightness from the center to the edge of the Sun was determined, along both polar and equatorial diameters, with the result that if any difference in these two directions existed, it was inappreciably small. At 98 per cent. of the radius from the center of the Sun's disk the radiation was found to have fallen off one-half, and it was noted with surprise that the umbra of a sun-spot appeared to emit more radiation than the still brilliant edge of the Sun's disk. A determination was made of the direct effect of sun-spots to diminish the total radiation of the Sun, and this, it was found, could rarely reach one-tenth of 1 per cent. Mr. Langley inferred from his experiments on the absorption of solar

radiation in the Sun's envelope that very great changes of the temperature of the Earth would be likely to result from reasonably conceivable variations in solar absorption; but these inferences, based on Newton's law of cooling, would now be subject to revision in the light of the present acceptation of Stefan's law of radiation. It is characteristic of Mr. Langley's caution, however, that he himself called attention to the uncertainty of these estimates and the hesitation with which he made them.

In 1901 the study of the distribution of radiation over the Sun's disk and in sun-spots was again taken up under Mr. Langley's direction at the Smithsonian Astrophysical Observatory, and since then by the aid of the sensitive automatic recording bolometer, not only the distribution of the total radiation, but that of many different parts of the spectrum between $0.4\,\mu$ and $2.5\,\mu$, has been determined on very numerous occasions both on the general photosphere and in spots. This work is not as yet fully published, but brief notices of it may be found in the *Reports* of the Smithsonian Institution.

(2) The solar energy-spectrum and its extension toward the infra-red.

Mr. Langley's primary object in devising the bolometer was to obtain an instrument for the study of the distribution of radiation in the solar spectrum, and in 1880, even before he had chosen the name "bolometer" for the new instrument, he employed it to determine for the first time the intensity of energy in the solar spectrum formed by a diffraction grating. He continued bolometric determinations of the prismatic solar energy-spectrum at Allegheny for several years, and was the first to obtain for infra-red work large, optically-good prisms of rock-salt. While on Mount Whitney in 1881 he discovered evidences of solar radiation extending beyond all previously known wave-lengths as far as $5\,\mu$ in the infra-red. After the foundation of the Smithsonian Astrophysical Observatory, and his introduction of automatic photographic recording devices for the bolometer, the infra-red solar spectrum was carefully explored under Mr. Langley's direction to fix the place of its absorption lines and bands, from $0.76\,\mu$ to $5.3\,\mu$. This work formed the principal matter of Volume I of the *Annals of the Astrophysical*

Observatory of the Smithsonian Institution. Still more recently the exact distribution of intensities in the solar spectrum from 0.37 μ to 2.5 μ has been studied at the Astrophysical Observatory under his direction, and brief mention of these results, as yet not fully published, may be found in the *Smithsonian Reports.*

(3) The lunar energy-spectrum and the probable temperature of the Moon.

Researches of the most extreme difficulty were carried on by Mr. Langley and Mr. Very from 1883 to 1888, at Allegheny, to determine the probable temperature of the Moon. These involved the study of the Moon's spectrum by the bolometer—a task which I venture to think few have the hardihood to repeat even now. For the temperature of the Moon is so low that its own proper spectrum differs little from that of the walls of the room, and all the other terrestrial surroundings, and its rays suffer the most variable and perplexing absorption from all the vapors of our atmosphere, including not only water and carbonic acid, but all the products of combustion of coal which pollute more and more the atmosphere over our cities. Mr. Langley has told the writer that none of his other researches cost him so much trouble with so little measure of satisfaction as this on the lunar temperature. He concluded finally that the Moon's temperature is a little above 0° Centigrade, but Mr. Very has more recently again worked over the material and has reached a result somewhat higher.

(4) Spectra of terrestrial sources, and the determination of hitherto unmeasured wave-lengths.

During the lunar research the energy-spectra of blackened metals at various temperatures were studied by Mr. Langley, but he did not proceed so far with this investigation as to derive experimentally the laws connecting radiation and temperature, though he wished very much to find time to do so. By combining two spectroscopes, one containing a Rowland grating and the other a rock-salt prism, he determined the dispersion of rock-salt as far as 5.3 μ in 1885. This dispersion-curve was again determined by his method, and under his direction, at the Smithsonian Observatory in 1898. A most interesting terrestrial source of radiation which he examined was the Cuban fire-fly, *Pyrophorus noctilucus,* whose light he com-

pared with that of the electric arc and other ordinary sources of illumination, and proved the immense relative economy of nature's source of light.

(5) The absorption of the Earth's atmosphere on the radiation of the Sun, and the determination of the solar constant of radiation.

Hardly had Mr. Langley fixed with fair precision the general form of the solar energy-spectrum, when he proceeded to determine the influence of the Earth's atmosphere to diminish solar radiation at the surface of the Earth. He readily observed that the air exerts both a general and a selective action in diminishing solar radiation; and that, while the former increases steadily from the extreme infra-red to beyond the visible limit of the violet, the latter comprises great bands of increasing intensity as we go farther and farther in the infra-red; so that at length the absorption is found to be total for very considerable gaps in the infra-red solar spectrum. The consideration of these differences in apparent atmospheric absorption led him to the weighty conclusion that the total effect of the atmosphere to diminish the solar radiation could not possibly be estimated without studying all parts of the spectrum separately in detail, and that all previous estimates of atmospheric absorption, based on actinometric or photometric measurements of the total radiation were necessarily too low. He was so profoundly convinced of the great practical utility and crying need of exact measurements, which could be used to determine the total amount of solar radiation as it reaches the outer limits of our atmosphere, that, after making preliminary measurements at Allegheny, he enlisted the aid of wealthy friends, and of the general government, to send out in 1881, and publish the results of, a solar-constant expedition under his direction to Mount Whitney in California.

The report of the Mount Whitney Expedition is a monument to the energy, perseverance, originality, and skill in observation of Mr. Langley, and reflects great credit also upon the wonderful experimental ability of the late Professor Keeler, whose assistance on the Mount Whitney expedition Mr. Langley ever spoke of in terms of the highest praise and gratitude. The difficulties overcome by Langley and Keeler in using the bolometer at Lone Pine and on Mount Whitney cannot in our day be adequately realized;

and it is wonderful with what a degree of substantial accuracy they were able, in those extraordinarily difficult conditions, to determine the form of the solar energy-spectrum, and the effect upon it of terrestrial absorption.

Soon after coming to the Smithsonian Institution, Mr. Langley, by his personal efforts and influence, founded the Smithsonian Astrophysical Observatory. His aim from its inception was to direct its studies in lines calculated to be of practical utility to mankind, by increasing knowledge of the natural agencies which control climate and life. Quoting from the introduction of the Mount Whitney report, he believed that

> If the observation of the amount of heat the Sun sends the Earth is among the most important and difficult in astronomical physics, it may be termed the fundamental problem of meteorology, nearly all whose phenomena would become predictable, if we knew both the original quantity and kind of this heat; how it affects the constituents of the atmosphere on its passage earthward; how much of it reaches the soil; how, through the aid of the atmosphere, it maintains the surface temperature of this planet; and how, in diminished quantity and altered kind, it is finally returned to outer space.

In his prior work with the bolometer he had never diverted time from use of it to perfect the instrument, but at the Astrophysical Observatory he introduced in 1892 a continuous automatic photographic registering device to record its indications. Thus it became possible to map in a few minutes the whole energy-spectrum of the Sun in a manner adapted to bring out details of it hitherto impossible to detect with years of work. With this powerful instrument the infra-red energy-spectrum of the Sun was carefully mapped from wave-length $0.76\,\mu$ to wave-length $5.3\,\mu$, revealing about 700 absorption lines and bands in this invisible region. This, with subsidiary investigations, formed the matter of the first volume of the *Annals* of the Astrophysical Observatory, published in 1900. At the conclusion of this work the activities of the observatory were directed toward the solution of that fundamental question: Is the emission of radiation by the Sun substantially constant in amount, or does it vary sufficiently to produce marked and predictable effects on the climate of the Earth? This investigation had not at the time of Mr. Langley's death been completed, but it had proceeded so far as to indicate a very strong probability that the solar radiation

outside the Earth's atmosphere varies notably and frequently, in a manner adapted to profoundly influence the temperature of the Earth.

The inventiveness of mind displayed by Mr. Langley in all his work is remarkable. Among many devices which he originated are means for determining times of transit without personal equation; means for observing sudden phenomena, by substituting the observation of a place for a time; the bolometer and its automatic registering devices, already mentioned; means for producing perfect seeing, by stirring the column of air traversed by the beam. He also reinvented, without knowledge of its earlier use, the principle of the cœlostat, and employed that instrument about 1880 at Allegheny.

Mr. Langley's published astronomical work is very extensive. The most important titles are as follows:

Minute Structure of the Solar Photosphere. *Am. Jour. Sci.*, **7**, 87–101, February 1874.

Comparison of Certain Theories of Solar Structure with Observation. *Am. Jour. Sci.*, **9**, 192–198, March 1875.

Sur la température relative des diverses régions du Soleil. Étude des radiations superficielles du Soleil. *Comptes Rendus*, **80**, 746–749, 819–822, 1875; **81**, 436–439, 1875.

Measurement of the Direct Effect of Sun-Spots on Terrestrial Climates. *Monthly Notices Royal Astronomical Society*, **37**, 5–11, November 1876.

Certain Remarkable Groups in the Lower Spectrum. *Proc. Am. Academy*, **14**, 92–105, 1878.

The Bolometer and Radiant Energy. *Proc. Am. Acad.*, **16**, 342–358, 1881.

The Selective Absorption of Solar Energy. *Am. Jour. Sci.*, **25**, 169–196, March 1883.

Experimental Determination of Wave-lengths in the Invisible Prismatic Spectrum. *Am. Jour. Sci.*, **27**, 169–188, March 1884.

The Amount of the Atmospheric Absorption. *Am. Jour. Sci.*, **28**, 163–180, September 1884.

Researches on the Solar Heat and its Absorption by the Earth's Atmosphere. A Report of the Mount Whitney Expedition. *Professional Papers, Signal Service*, No. XV, 1884.

The New Astronomy. *Century Magazine*, 1884–5.

On the Temperature of the Surface of the Moon. *Memoirs Nat. Acad. Sci.*, **3**, 1884.

Observations of Invisible Heat Spectra and the Recognition of Hitherto Unmeasured Wave-lengths. *Proc. Am. Assn.*, **34**, 1885, and *Am. Jour. Sci.*, **31**, 1–12, January 1886.

On Hitherto Unrecognized Wave-lengths. *Phil. Mag.*, **22**, 149–173, August 1886, and *Am. Jour. Sci.*, **32**, 83–106, August 1886.
The Temperature of the Moon. *Memoirs Nat. Acad. Sci.*, **4**, 107–212, 1887.
Energy and Vision. *Am. Jour. Sci.*, **36**, 359–379, November 1888.
The History of a Doctrine. *Am. Jour. Sci.*, **37**, 1–23, January 1889.
The Cheapest Form of Light. *Am. Jour. Sci.*, **40**, 97–113, August 1890.
Annals of the Astrophysical Observatory of the Smithsonian Institution. Vol. I, 1900.
Good Seeing. *Am. Jour. Sci.*, **15**, 89–91, February 1903.
The Solar Constant and Related Problems. *Astrophysical Journal*, **17**, 89–99, March 1903.
The 1900 Solar Eclipse Expedition of the Astrophysical Observatory of the Smithsonian Institution, 1904.

Mr. Langley was repeatedly honored by domestic and foreign scientific societies and institutions of learning. He was a correspondent of the Institute of France; a foreign member of the Royal Society of London, of the Royal Society of Edinburgh, and of the Accademia dei Lincei, of Rome; a member of the National Academy of Sciences, and many other American and foreign scientific societies. He received the degree of D.C.L. from Oxford, D.Sc. from Cambridge, and among numerous others the degree of LL.D. from the Universities of Harvard, Princeton, Michigan, and Wisconsin. He was awarded the Janssen medal of the Institute of France, the Rumford medal of the Royal Society of London, and of the American Academy of Arts and Sciences; the Henry Draper medal of the National Academy of Sciences, and others.

Mr. Langley's habit of mind led him to experimental work rather than to mathematical analysis. He was, nevertheless, an acute reasoner, and an excellent example of this is found in his proof of the necessity of dealing with homogenous rays in deter mining the solar constant of radiation. His attitude was rather that of the eager searcher for a reason for some phenomena that had excited his interest, than that of one who sees a gap in the advance of science, and feels that some good work ought to be put in there. Whether from natural disposition, or from deliberate conviction that time could be saved thereby, or both, his method of attack upon a new experimental problem was to make rough trials at once, to improve the method as experience dictated, and at length reach the final dispositions as the result of correcting this and that detail

after trial, rather than by first spending long and careful study over every detail before reducing any part of the work to practice. Whatever may be our views of the comparative merits of the two methods, there can be no question of his conspicuous success, and of the enormous amount and excellent character of his experimental work. A very valuable rule with him was to write down at the beginning of each day the object to be kept in view that day, to make clear notes of all observations and proposals, and to keep in the notebook itself all those scraps of writing or computing which are so often jotted on slips of paper and lost.

It has fallen to the writer to repeat many of the pioneer experiments made by Mr. Langley, employing apparatus which, through Mr. Langley's efforts and encouragement, had become a thousand times better adapted to the work than that which was at his disposal to make the original measurements. The instruments he had to work with from 1870 to 1888 were indeed so totally inadequate to the difficult measurements which his active pioneer instinct of investigation required of them, that it is little short of a miracle that he was able, even with the aid of the assistants of uncommon ability whom, with his keen discrimination of men, he employed, to obtain results even approximating the truth. But I have been again and again surprised and delighted to find that the experimental results which he published a quarter of a century ago represent almost exactly the mean of mine, and, so far as I am now aware, there is no single one of the pioneer observations on which Mr. Langley's reputation rests, which the improved devices of the present do not substantially confirm.

In his published papers, his lectures, and in all his correspondence, Mr. Langley exhibits a grace and clearness of style, and an accuracy in the choice of words, equaled by few professional writers. He could hardly satisfy his own demands in these particulars, however, for he was continually altering and improving the style in draft after draft, and even in printer's proofs. It was a primary object with him to present every subject he published so clearly and fully that each article would be complete in itself, and adapted to be read with interest by educated persons not specialists in the subject.

The secret of the success of this great man is easily found; for he combined with an eagerness to push on in scientific pursuits which amounted at times to impatience, a perseverance which no obstacles or failures could daunt; with great originality and inventiveness of mind, a breadth of view which appreciated the best in human life and thought; with ambition for success and distinction in his own work, the altruism which led him to direct that work to improve the condition of all mankind.

ON THE DISTRIBUTION OF BRIGHTNESS OF THE ULTRA-VIOLET LIGHT ON THE SUN'S DISK [1]

By K. SCHWARZSCHILD and W. VILLIGER

I

The decrease of brightness from the center toward the edge on the Sun's disk has frequently been a subject of investigation. From recent decades three precise series of measurements are available. In 1871 H. C. Vogel,[2] by making exposures on silver chloride paper, determined the decrease of brightness for all of the photographically active rays; in 1877[3] he observed visually with the spectral photometer a series of wave-lengths in the visible spectrum. Very[4] later investigated the distribution of brightness throughout the visible spectrum and on into the infra-red to λ 1.5 μ, with the bolometer.

The present investigation extends the range of wave-lengths toward the ultra-violet as far as λ 0.32. The method employed was the following: In Schott's Glass Works at Jena kinds of glass known as "ultra-violet glass" have been manufactured for some time, which show, in layers of several centimeters thickness, good transparency for the ultra-violet light from λ 0.30 downward. On the other side, it is known that thin layers of silver, which are entirely opaque to the longer wave-lengths and which are the best mirrors, lose their power of reflection quite suddenly in the region of about 0.34 μ, and become transparent. Professor R. Straubel conceived the idea of making a light-filter for ultra-violet light by covering such ultra-violet glass with a thin film of silver.

For just such solar photographs as we had in mind, this idea furnished an exceedingly simple procedure, in that nothing further was necessary than to silver the objective of ultra-violet glass, used in the observation, on one or more surfaces, in our case two. In order to be certain which wave-lengths were transmitted by the light-filter

[1] A preliminary communication, based upon a smaller number of plates, appeared in the *Physikalische Zeitschrift*, **6**, 737–744, 1905.

[2] *Sitzungsberichte der Berliner Akademie*, 1871.

[3] *Ibid.*, 1877.

[4] *Astrophysical Journal*, **16**, 73–91, 1902.

thus produced, Dr. Henker very kindly made several exposures to the iron spectrum with the help of this silvered objective. The result was that only a narrow strip of the spectrum, from wave-length 0.320 to 0.325 μ, was transmitted; and even with a decided overexposure this only extended from 0.315 to 0.327 μ.

The objective was of 120 mm clear aperture, of 325 cm focus, and was attached with its tube to the refractor of the experimental observatory of the Zeiss Works at Jena. In front of the plate an instantaneous shutter was fastened. With an exposure of about $\frac{1}{80}$ second, very sharp, normally exposed pictures of the Sun were obtained.

The photometric principle consisted in the use of sector diaphragms before the objective, which principle is entirely free from objection in measurements of surface brightness. The light was diaphragmed down to $\frac{1}{2}$ and $\frac{1}{4}$ by three sector openings each of either 60° or 30° angle.

The first photographs were taken two years ago, but there was a series of minor obstacles to be overcome before usable results could be obtained. At first three and four surfaces of the objective were silvered, making a long exposure time necessary which was unfavorable for the sharpness of the image of the Sun. Further, it appeared that the speed of the shutter changed during its passage over the plate. Hence only those measures could be employed which were referred to a diameter of the Sun perpendicular to the motion of the shutter. The speed of the shutter from one exposure to another seems to be sufficiently constant, as is shown in the results below. In order to avoid the effects of absorption of the Earth's atmosphere as much as possible, the observations were taken close to the meridian, the motion of the shutter was vertical, and it was upon the horizontal diameter of the Sun along which the distribution of brightness was measured.

On each plate, of size 9×12 cm, three exposures were made, with full aperture, and with the diaphragms $\frac{1}{2}$ and $\frac{1}{4}$.

In order further to weaken the effect of the different transparency of the silver film, or of the glass in different parts of the objective, the exposures were always repeated in three different positions of the sector diaphragm. The sequence of the images on the plate was also changed, so that the picture exposed with full aperture was sometimes

in the center and sometimes on the edge of the plate, since for a little while we had a suspicion that the parts around the edge of the plate were a little more strongly blackened with the same illumination. This precaution was observed later, although the suspicion was not confirmed in general.

A series of observations therefore finally consisted of six plates with three exposures each, in which the position of the diaphragms and the sequence of the pictures were changed in the manner indicated below.

The plates were measured at the Observatory at Göttingen with the Hartmann micro-photometer, with which the blackening of each part of the plate is compared with the blackening of a photographic wedge, and is numerically indicated in millimeters registering the amount of motion of the wedge. A measuring apparatus by Spindler and Hoyer was placed under the micro-photometer. This apparatus made it possible to read with certainty to $\frac{1}{100}$ mm the co-ordinates of the places photometrically measured. The measured spot itself had a diameter of 0.15 mm in the direction of the solar diameter under investigation; perpendicular to that, a diameter of 0.25 mm. It is possible to measure the blackening of a spot which is 0.07 mm distant from the edge, which for the size of the solar image is 0.005 of the radius, although on account of the rapid decrease of light toward the edge only a normal amount of accuracy can be obtained up to a distance of 0.15 mm from the edge.

Settings were first made under the measuring machine on the north and south edges of the Sun (the short side of the plate indicated the north and south directions with sufficient accuracy). The mean of the two readings gave the one co-ordinate of the solar diameter to be followed. Settings were then made on the east and west limbs of the Sun. The mean of these two settings gave the center of the Sun's image, and starting from this central position, settings were carried out at the distances given in the following table from east to west. The measurements were made by Herr E. Jastram.

After a great part of the measurements was completed, a source of error was noticed which occurs with Hartmann's micro-photometer if photometric measurements are made upon a very opaque portion of a plate in the immediate neighborhood of a larger area which is

very slightly opaque. The very bright light which then passes through the unblackened area is in part reflected at the objective of the observing microscope, and illuminates from in front the dark portion of the plate, so that it appears too bright. In the case of our measurements a very disturbing effect of this error could be noticed near the Sun's limb. It falsified the intensity deduced from the observations by 5 per cent. if the objective was clean, and by from 30 to 50 per cent. if dust had settled upon the objective so that it diffusely reflected still more light. The effect of the error was overcome by always covering the whole plate during the measurement by a black disk laid upon the plate and containing a small circular aperture only slightly larger than the spot to be measured. After the detection of this error, all the measures were repeated with the use of such a disk.

The following table gives the results of the new measurements for the five series of plates obtained last year. The second half of the last series had to be rejected, since the plates had received stray light. Subsequently plate No. 90 was also rejected, since the image obtained with the diaphragm $\frac{1}{2}$ differed too little from the image with the diaphragm $\frac{1}{4}$, and obviously the result was not the mean between the images with diaphragms 1 and $\frac{1}{4}$. In the following table ρ denotes the distance in millimeters from the center of the Sun's disk. The numbers following indicate the settings of the photometer wedge in millimeters. They are the means of two settings, one immediately following the other. It did not seem necessary to give both of the single settings, as they agreed always within a few tenths of a millimeter. Large readings in millimeters signify stronger degrees of blackening. The measured diameter of the image in millimeters is given below the photometer settings of every image.

TABLE I

SERIES I, MAY 28, 1905

ρ	Plate 66. Position I of Diaphragm						Plate 67. Position II of Diaphragm						Plate 68. Position III of Diaphragm					
	¼		½		1		¼		½		1		¼		½		1	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	52.4		57.4		62.1		53.2		58.8		62.5		52.6		57.3		62.7	
4.0....	52.1	52.1	57.2	56.9	61.8	61.6	52.9	52.1	58.7	58.1	62.1	62.3	52.2	52.1	57.2	56.8	62.6	62.3
8.0....	51.7	50.6	56.1	55.5	61.1	60.8	51.6	51.5	57.7	57.6	61.6	61.2	51.5	51.1	56.9	55.9	61.6	61.6
11.0....	48.8	48.7	54.6	54.3	60.1	60.1	49.4	49.1	55.9	55.1	61.1	60.1	49.2	48.7	54.7	54.6	60.2	60.1
13.0....	46.9	44.6	52.8	51.1	57.7	57.3	47.3	47.3	54.1	52.9	59.2	58.2	46.9	46.8	52.9	52.3	57.9	58.1
14.0....	43.9	41.8	50.5	49.1	56.4	55.2	42.1	42.6	51.5	50.3	57.3	56.1	42.3	42.9	50.1	50.1	56.8	55.4
14.5....	41.4	39.4	47.7	46.5	54.6	54.6	38.9	38.9	49.1	48.6	55.6	54.2	39.9	39.1	48.2	47.5	54.7	54.9
14.7....	37.6	37.3	46.1	44.6	53.3	53.7	35.2	37.6	47.2	46.8	53.6	53.7	38.1	37.5	45.8	46.1	53.2	53.7
14.8....	37.1	31.5	45.9	42.3	52.4	52.2	30.5	35.1	46.3	43.6	53.1	53.1	36.5	33.8	45.6	43.6	52.4	52.8
14.9....	30.1	—	42.8	40.8	50.5	49.6	—	26.1	42.1	39.6	47.5	52.2	33.1	28.1	43.2	38.3	50.1	50.9
15.0....	—	—	29.5	27.6	46.1	45.1	—	—	—	21.1	44.1	47.1	—	—	—	—	42.5	42.3
Diameter..	29.96		29.98		30.01		29.83		29.93		30.00		29.94		29.90		30.06	

ρ	Plate 69. Position III of Diaphragm						Plate 70. Position II of Diaphragm						Plate 71. Position I of Diaphragm					
	½		1		¼		½		1		¼		½		1		¼	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	60.1		65.7		56.1		59.1		63.1		53.8		56.8		61.7		51.4	
4.0....	59.3	59.4	65.5	64.9	55.1	55.6	58.2	58.2	62.4	62.8	53.2	53.5	56.1	56.5	61.1	61.3	51.1	51.1
8.0....	58.9	58.9	64.3	64.1	53.8	54.2	57.7	57.6	61.7	62.5	52.6	52.3	55.4	55.7	60.2	61.1	50.3	50.4
11.0....	57.2	57.1	63.1	62.9	51.7	52.3	56.3	56.4	60.8	61.1	51.2	51.1	54.1	54.6	59.1	60.5	48.7	48.1
13.0....	55.6	55.5	61.4	61.5	49.1	49.9	53.8	54.6	58.6	59.6	47.9	48.1	51.2	52.8	57.3	58.3	44.9	45.2
14.0....	54.1	53.1	60.3	59.6	46.4	47.5	51.9	52.1	57.3	57.3	46.7	45.7	49.7	50.3	55.1	56.2	42.3	42.3
14.5....	51.4	50.8	59.1	57.8	44.9	45.1	50.1	50.4	55.2	55.9	43.6	42.6	47.1	48.5	53.6	54.6	40.6	39.1
14.7....	49.1	49.2	57.8	56.9	40.7	42.5	48.5	48.5	54.6	54.3	40.9	39.7	44.6	47.1	52.3	53.1	39.0	37.5
14.8....	48.1	47.6	56.8	54.6	39.4	40.8	47.3	47.3	53.7	53.0	40.6	38.1	44.1	44.3	51.6	51.4	35.1	34.7
14.9....	47.3	45.1	55.8	50.6	29.5	37.1	44.3	42.1	51.9	50.7	37.7	31.6	41.8	41.5	50.1	50.4	30.1	27.1
15.0....	41.1	32.1	47.2	43.4	—	23.5	37.6	23.8	42.9	43.1	—	—	28.9	32.1	42.9	42.3	—	—
Diameter..	29.90		29.90		29.90		29.95		29.95		29.97		29.95		29.96		29.96	

TABLE I—*Continued*

SERIES II, JUNE 27, 1905

ρ	Plate 75. Position I of Diaphragm						Plate 76. Position II of Diaphragm						Plate 77. Position III of Diaphragm					
	¼		½		1		¼		½		1		¼		½		1	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	52.6		56.9		61.5		50.8		56.1		60.6		52.6		56.9		60.9	
4.0....	52.4	52.3	56.5	56.3	61.2	61.1	50.1	50.1	55.5	55.6	59.0	59.1	52.5	52.1	56.4	56.2	60.7	60.6
8.0....	52.1	50.9	55.8	55.7	60.5	60.8	49.1	48.7	55.1	54.6	58.6	57.9	51.1	51.4	56.1	55.6	60.1	60.2
11.0....	49.7	50.1	54.6	54.3	58.9	60.1	47.7	47.9	53.2	53.2	58.1	56.8	49.7	49.6	55.6	54.6	58.1	59.1
13.0....	48.2	48.2	52.6	52.6	56.9	58.4	46.1	46.1	52.8	51.7	55.7	55.5	48.2	47.2	52.9	52.9	56.4	56.8
14.0....	46.4	46.1	50.7	50.1	54.7	56.2	43.7	44.1	49.5	49.2	54.1	53.2	45.5	46.3	50.8	50.3	54.7	55.6
14.5....	45.2	43.6	49.2	48.7	53.2	54.8	42.5	41.5	47.6	47.8	52.9	51.6	43.7	43.9	48.4	48.8	53.3	53.3
14.7....	42.3	42.2	47.5	47.9	51.4	54.2	41.3	40.7	46.5	46.4	51.7	50.7	41.9	42.6	47.6	47.3	51.6	52.7
14.8....	41.7	41.3	46.3	47.1	50.1	53.1	40.8	39.9	45.1	45.2	50.9	49.5	41.7	41.7	46.1	46.2	51.1	51.4
14.9....	39.6	39.5	46.1	45.1	47.8	51.1	38.1	37.9	43.1	41.2	47.1	45.8	38.1	40.2	43.1	43.4	47.6	46.5
Diameter..	29.75		29.85		29.85		29.77		29.80		29.82		29.85		29.80		29.85	

ρ	Plate 78. Position III of Diaphragm						Plate 79. Position II of Diaphragm						Plate 80. Position I of Diaphragm					
	½		1		¼		½		1		¼		½		1		¼	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	58.3		63.9		53.2		59.7		65.1		54.2		58.1		61.8		51.5	
4.0....	58.1	58.0	63.5	62.8	52.9	53.1	59.8	59.6	64.4	64.9	53.7	53.7	57.9	57.8	61.5	61.9	51.2	50.1
8.0....	57.5	56.5	62.6	62.1	52.2	52.4	58.5	58.5	63.8	63.7	53.2	53.1	57.5	56.6	61.2	60.8	50.1	49.5
11.0....	55.7	55.7	60.7	60.7	51.1	50.8	57.5	57.1	62.5	62.6	51.6	51.8	56.1	55.5	59.9	59.7	48.5	48.4
13.0....	53.2	53.8	59.5	59.1	48.6	48.5	54.8	55.3	60.7	60.8	49.5	49.6	53.2	54.2	57.2	57.2	46.2	46.7
14.0....	51.8	51.5	57.1	56.8	45.8	46.1	52.8	53.2	58.6	59.1	47.3	47.7	51.4	51.8	55.5	56.7	44.1	45.5
14.5....	50.1	49.7	55.7	54.7	44.6	44.6	51.6	50.8	56.8	56.8	45.4	45.4	49.6	49.2	53.2	53.3	42.6	42.8
14.7....	49.6	48.2	54.6	53.5	42.6	42.2	50.1	49.1	54.6	55.5	43.1	43.7	47.7	47.6	52.3	52.6	40.7	41.7
14.8....	47.1	47.2	53.5	52.5	40.9	40.4	48.1	47.7	54.1	54.7	41.9	42.5	47.5	46.4	51.2	51.3	40.2	41.1
14.9....	43.6	43.2	49.3	49.7	38.5	38.2	42.6	43.4	47.6	52.1	39.1	37.5	43.2	42.8	48.9	48.4	37.6	38.1
Diameter..	29.80		29.85		29.79		29.80		29.85		29.85		29.87		29.83		29.82	

TABLE I—*Continued*

SERIES III, JULY 26, 1905

ρ	Plate 87. Position I of Diaphragm						Plate 88. Position II of Diaphragm						Plate 89. Position III of Diaphragm					
	¼		½		1		¼		½		1		¼		½		1	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	52.1		59.6		65.3		51.8		58.8		64.4		50.5		56.1		60.7	
4.0....	51.9	51.7	58.9	59.2	64.6	64.5	51.5	51.5	58.2	57.9	64.1	63.8	50.1	49.9	55.8	55.6	60.1	60.1
8.0....	49.6	49.7	58.5	58.3	63.9	63.8	50.8	49.7	57.6	56.7	63.5	63.2	49.1	48.7	54.6	55.2	59.5	59.9
11.0....	48.1	47.8	56.3	56.6	63.2	62.7	48.2	46.7	55.9	55.1	62.6	61.2	46.4	46.2	53.5	53.2	57.8	58.8
13.0....	44.5	45.2	53.2	53.5	60.8	60.2	45.4	43.8	52.8	52.2	60.2	59.6	45.0	42.5	50.9	51.4	55.7	56.8
14.0....	40.6	40.7	51.1	50.9	58.7	58.4	40.9	39.6	50.6	49.1	57.6	58.1	40.7	39.2	48.2	48.2	54.1	55.4
14.5....	35.5	35.5	47.8	48.8	56.1	55.5	34.5	31.5	47.3	44.7	54.7	55.5	36.1	32.5	45.3	45.1	52.3	53.1
14.7....	32.3	33.6	44.7	45.1	55.5	54.1	—	—	44.3	42.3	53.5	53.7	—	22.6	42.2	42.4	50.1	52.4
14.8....	25.7	27.1	44.1	43.1	54.6	52.1	—	—	42.3	39.6	51.6	52.5	—	—	40.9	40.1	49.6	51.1
14.9....	—	—	39.6	38.5	50.5	47.1	—	—	39.1	37.1	48.4	49.7	—	—	36.2	35.5	45.1	48.1
Diameter..	29.85		29.90		29.93		29.85		29.86		29.90		30.00		29.90		29.95	

ρ	Plate 91. Position II of Diaphragm						Plate 92. Position I of Diaphragm					
	½		1		¼		½		1		¼	
	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	60.0		65.3		53.0		59.1		65.8		53.7	
4.0....	59.4	59.6	64.8	65.1	52.7	52.6	58.6	58.2	65.4	65.1	53.6	52.3
8.0....	57.8	58.2	64.3	64.4	51.4	51.1	57.7	56.9	63.9	64.5	51.6	51.8
11.0....	56.2	57.1	63.2	63.4	49.5	48.7	56.3	55.4	63.3	62.8	49.3	49.1
13.0....	53.5	54.1	60.1	61.2	45.3	45.5	53.8	52.6	61.1	60.1	44.8	45.4
14.0....	50.1	51.2	58.1	59.5	40.9	40.1	51.1	49.6	59.3	57.8	40.1	40.8
14.5....	47.6	47.5	55.6	56.3	35.1	33.2	48.1	45.1	56.2	54.7	36.5	34.4
14.7....	45.4	44.1	54.8	55.1	29.8	—	45.9	42.8	54.8	53.7	—	—
14.8....	42.7	41.3	52.9	52.4	—	—	43.9	39.7	53.1	51.9	—	—
14.9....	39.8	34.8	49.1	47.8	—	—	41.1	33.7	49.4	49.2	—	—
Diameter..	29.85		29.85		29.84		30.00		29.95		29.89	

TABLE I—*Continued*

SERIES IV, SEPTEMBER 8, 1905

ρ	Plate 103. Position I of Diaphragm						Plate 104. Position II of Diaphragm						Plate 105. Position III of Diaphragm					
	¼		½		1		¼		½		1		¼		½		1	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	49.3		55.3		60.1		48.6		54.3		59.6		49.2		55.6		60.1	
4.0....	49.1	48.5	54.8	54.9	60.1	59.1	48.1	47.9	53.7	53.5	59.3	59.2	48.8	48.5	55.2	54.8	59.8	59.8
8.0....	47.8	47.8	54.1	54.5	59.6	58.5	46.7	47.1	52.6	52.5	57.9	57.8	47.1	47.5	54.6	54.3	58.7	59.4
11.0....	45.6	45.9	52.7	52.6	57.8	57.6	45.2	44.5	51.7	51.8	57.2	56.7	45.6	44.8	54.1	52.1	57.8	57.7
13.0....	42.7	42.6	50.1	51.1	54.9	55.5	42.7	40.8	49.6	49.1	55.1	55.1	41.8	42.7	51.1	51.1	57.0	56.2
14.0....	39.6	40.6	48.8	48.6	54.1	53.7	39.3	38.4	49.1	46.8	53.7	53.7	38.7	39.1	49.7	48.7	55.1	55.1
14.5....	36.2	38.7	46.7	46.2	52.6	52.5	34.2	35.4	45.2	45.1	52.3	52.2	35.5	36.2	48.7	46.5	53.7	54.1
14.7....	32.9	34.5	44.9	44.5	51.5	51.1	31.4	32.1	43.7	42.6	50.5	51.0	32.5	32.1	47.3	44.4	52.6	52.5
14.8....	32.1	33.3	44.3	43.7	51.2	50.7	27.5	27.9	43.1	41.6	50.1	50.5	28.6	30.1	46.1	43.7	51.7	52.0
14.9....	22.5	26.4	42.7	41.8	49.1	49.7	—	19.7	41.8	38.9	49.2	49.1	—	21.4	44.1	41.6	50.8	51.2
15.0....	—	16.3	38.2	38.2	46.7	47.1	—	—	37.5	34.6	46.6	45.6	—	—	40.4	34.1	46.5	46.4
Diameter..	30.10		30.10		30.10		30.03		30.07		30.10		30.00		30.10		30.12	

ρ	Plate 106. Position III of Diaphragm						Plate 107. Position II of Diaphragm						Plate 108. Position I of Diaphragm					
	¼		1		½		¼		1		½		¼		1		½	
	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West	East	West
0.0....	52.4		63.2		57.3		52.3		62.5		58.0		53.5		64.1		58.4	
4.0....	52.1	51.7	62.8	62.8	57.1	56.8	52.1	51.8	62.4	62.1	57.6	57.1	53.2	52.3	63.8	63.2	58.2	57.9
8.0....	50.9	50.6	61.3	62.1	56.8	55.9	51.1	50.9	61.3	61.3	56.7	55.6	52.3	51.9	63.1	62.2	57.5	57.3
11.0....	49.3	49.3	60.2	61.1	55.1	54.6	50.1	48.5	59.9	59.8	55.7	55.3	51.1	50.6	61.8	61.1	56.3	55.2
13.0....	46.1	46.1	57.9	59.1	52.3	53.1	46.8	46.9	58.7	57.9	53.6	53.4	48.0	48.2	60.5	59.3	54.9	53.9
14.0....	43.6	42.5	56.1	57.6	50.1	50.1	45.3	44.6	57.0	56.8	51.3	51.3	45.7	46.1	58.7	57.0	53.1	52.1
14.5....	39.1	40.1	54.3	56.1	48.4	48.7	42.4	42.4	55.5	55.5	49.5	49.1	43.8	44.9	57.5	55.7	50.5	50.6
14.7....	37.8	36.8	53.5	55.0	47.2	46.7	41.3	40.2	55.1	54.1	48.3	48.9	41.4	42.1	56.8	54.3	50.1	49.4
14.8....	37.3	35.7	52.8	54.2	45.8	46.2	40.6	38.8	54.1	53.5	47.2	47.5	40.1	41.4	55.7	54.1	48.7	48.3
14.9....	32.6	31.9	51.3	52.8	43.7	43.9	38.9	36.0	53.2	52.1	45.1	46.9	35.8	40.4	54.6	53.2	47.6	46.5
15.0....	29.2	27.3	48.1	50.8	42.5	40.1	32.7	29.1	49.1	49.4	40.1	42.1	31.7	36.2	49.7	50.5	43.1	43.3
Diameter..	30.10		30.10		30.10		30.10		30.10		30.10		30.10		30.10		30.10	

SERIES V. OCTOBER 15, 1905

ρ	PLATE 110. POSITION I OF DIAPHRAGM					
	¼		½		1	
	East	West	East	West	East	West
0.0....	50.8		56.7		60.9	
4.0....	50.3	50.1	55.8	56.1	60.9	61.1
8.0....	49.2	49.4	55.5	55.5	60.1	60.1
11.0....	48.1	47.8	53.7	54.4	58.8	59.4
13.0....	45.6	45.3	51.9	52.7	57.7	58.6
14.0....	43.6	42.1	49.5	50.1	56.1	57.2
14.5....	40.8	40.6	47.6	48.3	54.6	55.1
14.8....	40.3	37.6	44.6	47.1	53.2	54.6
15.0....	32.3	33.2	42.8	44.1	52.1	53.5
15.1....	28.7	28.6	42.2	43.2	51.3	53.1
15.2....	—	25.1	36.6	40.1	45.8	49.1
Diameter..	30.45		30.50		30.50	

ρ	PLATE 111. POSITION II OF DIAPHRAGM					
	¼		½		1	
	East	West	East	West	East	West
0.0....	50.4		55.8		60.5	
4.0....	50.2	49.8	55.7	55.2	60.1	60.2
8.0....	49.1	49.0	54.6	54.5	60.0	59.5
11.0....	47.6	46.9	53.2	53.1	58.9	59.1
13.0....	45.6	44.6	52.6	51.1	56.6	57.6
14.0....	43.7	42.2	49.5	49.2	55.1	55.9
14.5....	40.5	39.8	48.2	46.6	54.6	55.1
14.8....	38.2	38.3	46.9	44.8	53.2	53.7
15.0....	37.5	35.5	45.0	43.1	51.8	52.8
15.1....	36.9	33.1	43.7	40.6	51.1	51.4
15.2....	26.2	23.2	36.6	34.1	43.8	45.5
Diameter..	30.50		30.50		30.50	

ρ	PLATE 112. POSITION III OF DIAPHRAGM					
	¼		½		1	
	East	West	East	West	East	West
0.0....	50.6		55.7		59.9	
4.0....	50.1	50.1	55.6	54.7	59.2	59.5
8.0....	49.6	49.3	55.1	54.3	58.8	58.7
11.0....	48.1	47.6	54.3	52.6	58.6	57.7
13.0....	46.7	45.1	51.8	50.9	57.1	55.8
14.0....	44.5	42.2	50.6	48.7	55.6	55.1
14.5....	42.7	40.7	48.7	46.9	54.0	53.3
14.8....	40.5	37.5	47.3	45.5	53.1	52.5
15.0....	39.1	35.4	45.2	43.7	51.7	51.5
15.1....	38.2	32.3	44.6	40.5	51.1	50.1
15.2....	27.9	20.1	37.6	37.2	44.8	46.1
Diameter..	30.50		30.50		30.50	

To compress these numbers, the mean was then taken for the points equally distant from the center east and west. The values thus obtained were again combined into a mean for each set of similar plates which had been exposed with three different settings of the diaphragm. In this way the following series of values were obtained.

TABLE II

ρ	Plates 66–68			Plates 69–71			Plates 75–77			Plates 78–80		
	1	½	¼	1	½	¼	1	½	¼	1	½	¼
0.0	62.4	57.8	52.7	63.5	58.7	53.8	61.0	56.6	52.0	63.6	58.7	53.0
4.0	62.1	57.5	52.3	63.0	58.0	53.3	60.3	56.1	50.9	63.2	58.6	52.6
8.0	61.3	56.6	51.4	62.3	57.4	52.3	59.7	55.5	50.6	62.4	57.5	51.8
11.0	60.3	54.9	49.0	61.3	56.0	50.5	58.5	54.3	49.1	61.0	56.3	50.4
13.0	58.1	52.7	46.7	59.5	53.9	47.5	56.6	52.6	47.3	59.1	54.1	48.2
14.0	56.2	50.4	42.6	57.7	51.9	45.2	54.8	50.1	45.4	57.3	52.1	46.1
14.5	54.8	47.9	39.9	56.1	49.7	42.7	53.2	48.4	43.4	55.1	50.0	44.2
14.7	53.6	46.1	37.2	54.9	47.9	40.1	52.1	47.2	42.0	53.9	48.7	42.3
14.8	52.7	44.7	34.1	53.6	46.5	38.1	51.0	46.0	41.2	52.9	47.4	41.2
14.9	50.2	41.1	—	51.6	43.7	32.2	47.7	43.7	38.9	49.4	43.1	38.2
15.0	49.5	—	—	43.6	32.6	—	—	—	—	—	—	—
Diameter	30.02	29.94	29.91	29.94	29.93	29.94	29.84	29.82	29.79	29.84	29.82	29.82

TABLE II—*Continued*

ρ	Plates 87–89			Plates 91–92			Plates 103–105		
	1	½	¼	1	½	¼	1	½	¼
0.0	63.5	58.2	51.5	65.6	59.6	53.4	59.9	55.1	49.0
4.0	62.9	57.6	51.1	65.2	59.0	52.9	59.6	54.5	48.5
8.0	62.3	56.8	49.6	64.3	57.7	51.5	58.7	53.8	47.3
11.0	61.1	55.1	47.3	63.2	56.3	49.2	57.5	52.5	45.3
13.0	58.9	52.4	44.4	60.7	53.5	45.3	55.6	50.4	42.6
14.0	56.1	49.7	40.3	58.7	50.5	40.5	54.2	48.6	39.3
14.5	54.5	46.5	34.3	55.8	47.1	34.9	52.9	46.4	36.1
14.7	53.2	43.6	—	54.7	44.6	—	51.6	44.6	32.9
14.8	52.0	41.7	—	52.6	41.9	—	51.1	43.8	29.9
14.9	48.2	37.7	—	48.9	37.4	—	49.9	41.9	21.9
15.0	—	—	—	—	—	—	46.5	37.2	—
Diameter	29.93	29.89	29.90	29.90	29.92	29.87	30.11	30.09	30.04

TABLE II—*Continued*

ρ	Plates 106–108			Plates 110–112		
	1	$\frac{1}{2}$	$\frac{1}{4}$	1	$\frac{1}{2}$	$\frac{1}{4}$
0.0	63.3	57.9	52.7	60.3	56.1	50.6
4.0	62.9	57.5	52.2	60.2	55.6	50.1
8.0	61.9	56.7	51.3	59.6	54.9	49.3
11.0	60.7	55.4	49.8	58.8	53.6	47.7
13.0	58.9	53.5	47.0	57.3	51.9	45.5
14.0	57.2	51.3	44.7	55.9	49.6	43.1
14.5	55.8	49.5	41.8	54.5	47.7	40.9
14.7	54.8	48.8	40.0	—	—	—
14.8	54.1	47.3	39.0	53.4	46.1	38.7
14.9	52.9	45.6	36.0	—	—	—
15.0	49.6	41.9	31.1	52.2	44.0	35.5
15.1	—	—	—	51.4	42.5	33.0
15.2	—	—	—	45.9	37.1	24.6
Diameter	30.10	30.10	30.10	30.50	30.50	30.48

The further problem consisted in determining the relation between the photometer readings and the light-intensities to which the plate was exposed.

We shall express all data as to brightness in astronomical magnitudes. The relation between m and the light-intensity J is defined by the well-known equation:

$$m = -2.5 \log J .$$

Diaphragming down to $\frac{1}{2}$ signifies therefore a loss of light of $2.5 \log \frac{1}{2}$ or 0.753 magnitudes. We will now designate the brightness in the Sun's image at a certain distance from the center with m_1, m_2, m_3, according as the light is diaphragmed down to 1, $\frac{1}{2}$, or $\frac{1}{4}$. Let the corresponding blackenings (photometer readings) be S_1, S_2, and S_3.

Then we have:

$$m_1 = m_2 - 0.753, \quad m_3 = m_2 + 0.753 . \qquad (1)$$

Since the exposure time for all photographs was the same, the blackening is simply a function of the brightness: $S = \Phi(m)$. The following equations therefore obtain:

$$S_1 = \Phi(m_2 - 0.753), \quad S_2 = \Phi(m_2), \quad S_3 = \Phi(m_2 + 0.753) ;$$

or, by inversion,

$$m_2 = \Psi(S_1) + 0.753 = \Psi(S_2) = \Psi(S_3) - 0.753 . \qquad (2)$$

The function Ψ is to be determined to satisfy these conditions. This is a problem in interpolation, which we shall treat more fully elsewhere. We now come to our purpose as follows.

Let the three following possibilities be considered:

α) If the relation between magnitudes and opacities were a linear one,

$$m=a-bS\ , \tag{3}$$

it would follow that

$$S_1-S_2=S_2-S_3=\frac{0.753}{b}\ ,$$

or the difference of the opacities of corresponding points on the Sun would have to be constant for different degrees of diaphragming.

β) Were the relation between magnitudes and opacities logarithmic,

$$m=\alpha \log(\beta+S)\ , \tag{4}$$

we should have

$$\begin{aligned} S_1&=\beta(\gamma-1)+\gamma S_2\ , \\ S_2&=\beta(\gamma-1)+\gamma S_3\ , \end{aligned} \tag{5}$$

where for abbreviation we place

$$\log\gamma=-\frac{0.753}{\alpha}\ . \tag{6}$$

There would thus be a linear relation between the opacities belonging together.

γ) Finally, let us assume that the function Ψ is of such a nature that its third derivatives may be neglected for the interval S_1 to S_2 or S_2 to S_3. Then we may write, in place of (2)

$$\begin{aligned} 0.753&=\Psi(S_2)-\Psi(S_1)=\Psi'\left(\frac{S_1+S_2}{2}\right)\cdot(S_2-S_1) \\ 0.753&=\Psi(S_2)-\Psi(S_3)=\Psi'\left(\frac{S_2+S_3}{2}\right)\cdot(S_3-S_1)\ ; \end{aligned} \tag{7}$$

or, if for brevity we make

$$\frac{S_1+S_2}{2}=T\ ,\quad \frac{S_2+S_3}{2}=T'\ ,\quad S_2-S_1=D\ ,\quad S_3-S_2=D'\ , \tag{8}$$

$$0.753=\frac{d\Psi}{dT}D=\frac{d\Psi}{dT'}D'\ .$$

By integrating, we obtain

$$\Psi(T)=0.753\int^T\frac{dT}{D}=0.753\int^T\frac{dT'}{D'}\ . \tag{9}$$

We therefore have to treat the reciprocal difference of the related opacities as a function of the mean T of the two opacities, and to integrate in order to obtain the desired function Ψ — the magnitude m belonging to each opacity T. The constant of integration—i. e., the starting-point for computing magnitudes—remains undetermined and a matter of indifference.

The three possibilities just described will in general give the necessary means of determining the function Ψ.

In our case the procedure was as follows:[1] It is easy to see that the related values of the opacities S_1, S_2, S_3, which in Table II are placed next each other, to some extent progress in a linear fashion. If we choose the coefficients β and γ in the relations (5) so that the actual dependence of the opacities is approximately reproduced, and if we then compute for each opacity S a quantity s by the formula

$$s=\alpha \log (\beta+S) , \tag{10}$$

then this quantity s will represent a sort of corrected opacity which will correspond very closely to the magnitudes. If we therefore seek further for the precise relation between s and the magnitude m; $m=\psi(s)$. Then we can make the assumption mentioned under γ, that the higher derivatives of ψ may be neglected, and therefore we may find ψ corresponding to (8) and (9) by forming

$$t=\frac{s_1+s_2}{2} , \quad t'=\frac{s_2+s_3}{2} , \quad s_2-s_1=\Delta , \quad s_3-s_2=\Delta', \tag{12}$$

$$\psi(t)=0.753\int^t\frac{dt}{\Delta}=0.753\int^t\frac{dt'}{\Delta'} . \tag{13}$$

In practice the following small modification of this scheme was found necessary. (13) gives two independent determinations of the function ψ, one from the exposures with diaphragms 1 and $\frac{1}{2}$, a second from those with diaphragms $\frac{1}{2}$ and $\frac{1}{4}$. There almost always appeared to be a small systematic difference between the two determinations of the function ψ, due to the fact that the sectors of the diaphragms have not precisely the prescribed dimensions; an exact

[1] The relation between magnitudes and opacities was too far from being linear in the case of several plates to make it advisable to use the simple adjustment employed in our previous communication. We therefore preferred to use the more inconvenient but systematic reduction throughout.

measurement of the sectors used by us yielded the actual values of 0.767 and 0.759 mag.; and that further differences arise from a change in the transparency of the air or in the velocity of the shutter. We shall therefore assume that the true values of the degree of diaphragming from 1 to $\frac{1}{2}$ and from $\frac{1}{2}$ to $\frac{1}{4}$ equal certain values a and b, and that only the total difference between the diaphragming for 1 and $\frac{1}{4}$ equals the prescribed values 0.767 and 0.759. In other words, we assume in place of (1)

$$m_1=m_2-a\ ,\quad m_3=m_2+b\ ,\quad a+b=1.527 \text{ mag.} \tag{14}$$

We therefore have in place of (13)

$$m=\psi(t)=a\int^t\frac{dt}{\Delta}=b\int^t\frac{dt'}{\Delta'}\ . \tag{15}$$

Hence for the differences Δ and Δ' which pertain to equal values of t and t',

$$\frac{\Delta}{a}=\frac{\Delta'}{b}\ . \tag{16}$$

The ratio $\frac{a}{b}$ is therefore to be determined from the average ratio of the differences Δ and Δ'.

In the actual employment of this process the differences Δ and Δ' were entered as the ordinates for the abscissae t and t' in the same figure, which gave two different curves. The ordinates of the second curve were then enlarged in a ratio $\frac{a}{b}$, which brought the two curves into the best possible conformity; and finally a new curve was drawn which followed the mean position between the first curve and the second curve enlarged. From this the differences Δ were then taken off as functions of t, and then by the first of the formulæ (15) m, the function sought, was computed by mechanical quadrature.

We give as an example to render clear the whole process, the group of Plates 66 to 68 in the second and fourth column of Table II. By graphically entering S_1 as a function of S_2, and S_2 as a function of S_3, it was found that with some degree of approximation the following linear relations held good:

$$S_1=0.755\,S_2+18.14 \text{ and } S_2=0.755\,S_3+18.14\ .$$

The comparison with (5) and (6) gives

$$\beta(\gamma-1)=18.14\ ;\quad \gamma=0.755\ ;\quad a=-\frac{0.753}{\log\gamma}\ ;$$

whence

$$\beta=-74.0\ ;\quad a=6.18\ .$$

And therefore by (10) $s=6.18\log(S-74.0)$. A "corrected" opacity s was now computed by this formula for every opacity S, with the resulting values s_1, s_2, s_3, given in the following table (for convenience all have been diminished by 6.18):

ρ	s_1	s_2	s_3	t	Δ	t'	Δ'	From Curve t	From Curve Δ
0.0	0.40	1.30	2.03	0.85	0.90	1.66	0.73	0.8	0.900
4.0	0.47	1.35	2.08	0.91	.88	1.72	.74	1.0	.870
8.0	0.64	1.49	2.19	1.07	.84	1.84	.70	1.2	.850
11.0	0.85	1.74	2.46	1.29	.89	2.10	.72	1.4	.830
13.0	1.24	2.03	2.69	1.63	.79	2.36	.66	1.6	.805
14.0	1.54	2.30	3.07	1.92	.76	2.69	.77	1.8	.785
14.5	1.75	2.58	3.29	2.16	.83	2.94	.71	2.0	.790
14.7	1.92	2.76	3.50	2.34	.84	3.13	.74	2.2	.810
14.8	2.03	2.89	3.71	2.46	.86	3.30	.82	2.4	.830
14.9	2.33	3.19		2.76	.86			2.6	.840
15.0	2.40							2.8	.855
								3.0	.855

The mean values t and t', and the appropriate differences Δ and Δ' of the consecutive values of s, were now formed. The graphical process described above gave $\frac{\Delta}{\Delta'}=\frac{a}{b}=1.14$; $a=0.814$ mag.; $b=0.713$ mag.; and the smoothed-out values of Δ given in the table. Then the first integral of (15) was formed simply by the trapezoidal rule, which yielded the function ψ sought for. The following table for ψ resulted:

s	$m=\psi(s)$	s	$m=\psi(s)$
0.4	2.59 mag.	2.0	1.08 mag.
0.6	2.42	2.2	0.87
0.8	2.26	2.4	0.67
1.0	2.07	2.6	0.48
1.2	1.88	2.8	0.29
1.4	1.69	3.0	0.10
1.6	1.49	3.2	−0.09
1.8	1.29	3.4	−0.27

With this we could finally convert the values s_1, s_2, s_3, into magnitudes. The results were as follows:

ρ	m_1	m_2	m_3	m_1-m_2	m_2-m_3
0.0	2.59	1.79	1.03	0.80	0.76
4.0	2.53	1.74	1.00	.79	.74
8.0	2.38	1.60	.83	.78	.72
11.0	2.21	1.35	.61	.86	.74
13.0	1.84	1.05	.37	.79	.68
14.0	1.54	0.76	.03	.78	.73
14.5	1.34	0.50	−.17	.84	.67
14.7	1.17	0.33	−.37	.84	.70
14.8	1.05	0.20	−.56	.85	.76
14.9	0.74	−0.09		.83	
15.0	0.67				

The differences m_1-m_2 and m_2-m_3 have, in fact, become constant within the limits of accidental errors, which confirms the fact that the opacities corresponding to the conditions (14) are thus transformed into magnitudes.

If desired, the value s can subsequently be rejected, as that only constitutes an intermediate step, and by a combination of (10) and the table for $\psi(s)$, a table may be constructed by which we may pass directly from the opacities S to magnitudes. This procedure was employed in what follows. Table III contains the

TABLE III

S	Plate Numbers								
	66–88	69–71	75–77	78–80	87–89	91–92	103–105	106–108	110–112
	mag.	mag.	mag.	mag.	mag.	mag.	mag.	mag.	mag.
66						2.48			
62	2.51	2.76	3.43	2.64	2.25	1.86		2.64	3.64
58	1.82	2.10	2.76	2.04	1.69	1.37	2.39	2.05	2.80
54	1.23	1.52	2.08	1.46	1.22	0.94	1.80	1.47	2.13
50	0.72	1.03	1.45	0.91	0.80	0.55	1.28	0.98	1.63
46	0.33	0.61	0.82	0.38	0.46	0.24	0.86	0.58	1.19
42	−0.01	0.24	0.17	−0.12	0.17	−0.02	0.52	0.22	0.82
38	−0.31	−0.05			−0.08	−0.28	0.26	−0.06	0.49
34	−0.57	−0.31			−0.27	−0.48	0.06	−0.31	0.21
30							−0.07	−0.54	−0.03
26							−0.18		−0.23
22							−0.27		−0.42
a	0.814	0.825	0.724	0.730	0.763	0.837	0.730	0.784	0.834
b	0.713	0.702	0.803	0.797	0.764	0.690	0.797	0.743	0.693

transformation table of the opacities into magnitudes for all the groups of plates. The values of *a* and *b* obtained are given every time at the foot of the table, which gives a certain insight into the trustworthiness of the diaphragming.

Thus all the data needed for the reduction of the plates are given.

III

With the aid of the above tables all of the opacities given in Table II were converted into magnitudes. The numbers in each column were then subtracted from the number at the head of the column, which corresponded to the brightness at the Sun's center, so that the resulting differences gave directly the decrease in the brightness of the Sun from the center. The mean was taken of the three series of numbers resulting for each group. Thus the conversion of the opacities into magnitudes furnished for the group of plates 66–68 the three series given above for m_1, m_2, m_3. The subtraction from the number at the top of each column yielded the values M_1, M_2, M_3, the mean of which is given under M.

ρ	M_1	M_2	M_3	M
0.0	0.00	0.00	0.00	0.00
4.0	0.06	0.05	0.03	0.05
8.0	0.21	0.19	0.15	0.18
11.0	0.38	0.44	0.42	0.41
13.0	0.75	0.74	0.66	0.72
14.0	1.05	1.03	1.00	1.03
14.5	1.25	1.29	1.20	1.25
14.7	1.42	1.46	1.40	1.43
14.8	1.54	1.59	1.59	1.57
14.9	1.85	1.88		1.87
15.0	1.92			1.92

A final correction is to be applied to these measures on account of the varying diameter of the Sun's image. As may be seen from the data at the foot of Table II, the weakest image was smaller by 0.02 mm or 1.′3, the strongest image larger by a similar amount than the average image. The impression is in fact given that, with diaphragm $\frac{1}{4}$, the Sun's limb is not quite sufficiently exposed, that the image with full aperture may suffer a little from irradiation on the film, and that the mean image yields the most trust-

worthy value of the diameter. On these images the edge is sharply defined to 0.01 mm under the microscope, and just outside the disk there is clear glass. The diameter of the image from the diaphragm $\frac{1}{2}$ is therefore taken as the standard, and its mean value for each group is used, as given at the foot of Table II; for instance, 29.94 for the group 66–68. With this the distances from the center of the disk, ρ, were converted into decimals of the Sun's radius. Finally the brightnesses were interpolated for the arbitrarily chosen standard value x of the distance from the center.

A similar treatment of all the groups of plates yielded the following nine series of values, the mean of which is to be regarded as the final result of this investigation. The differences from the mean are added, and the last column gives the light-intensity corresponding to the difference in magnitude, the intensity of the center of the disk being taken as unity.

TABLE IV

x	66–68	69–71	75–77	78–80	87–89	91–92	103–106	106–108	110–112	Mean
										mag.
0.000..	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
0.267..	0.05	0.09	0.13	0.05	0.07	0.06	0.06	0.06	0.05	0.070
0.533..	0.18	0.20	0.21	0.18	0.18	0.21	0.19	0.18	0.16	0.188
0.733..	0.40	0.39	0.42	0.38	0.38	0.38	0.38	0.37	0.36	0.384
0.867..	0.70	0.70	0.69	0.65	0.64	0.68	0.64	0.63	0.63	0.662
0.933..	1.01	0.95	1.01	0.91	0.94	0.95	0.86	0.89	0.91	0.937
0.967..	1.23	1.18	1.29	1.20	1.18	1.25	1.07	1.13	1.15	1.187
0.980..	1.38	1.35	1.45	1.34	1.33	1.36	1.23	1.26	1.34	1.338
0.987..	1.57	1.49	1.54	1.43	1.45	1.51	1.34	1.39	1.45	1.457
0.993..	1.75	1.74	1.72	1.60	1.65	1.76	1.58	1.64	1.64	1.676
0.997..	1.93	1.92	1.92	1.81	1.82	1.94	1.76	1.83	1.96	1.877

Differences from the Mean (Unit 0.01 mag.)									Mean Error	y
66–68	69–71	75–77	78–80	87–89	91–92	103–106	106–108	110–112		
									mag.	
0	0	0	0	0	0	0	0	0	0.000	1.000
−2	+2	+6	−2	0	−1	−1	−1	0	0.008	0.938
−1	+1	+2	−1	−1	+2	0	−1	−3	0.005	0.841
+2	+1	+4	0	0	0	0	−1	−2	0.006	0.702
+4	+4	+3	−1	−2	+2	−2	−3	−3	0.010	0.544
+7	+1	+7	−3	0	+1	−8	−5	−3	0.017	0.422
+4	−1	+10	+1	−1	+6	−12	−6	−4	0.024	0.335
+4	+1	+11	0	−1	+2	−11	−8	0	0.019	0.292
+5	+3	+8	−3	−1	+5	−12	−7	−1	0.021	0.261
+7	+6	+4	−8	−3	+8	−10	−4	−4	0.023	0.214
+5	+4	+4	−7	−6	+6	−12	−5	+8	0.024	0.178

In regard to the question of the reliability of these values, if the precision of the double settings of the Hartmann micro-photometer be taken as 2 per cent., a mean error of 0.002 mag. would result from the measures of the seventy-eight plates. It is evident at a glance that this precision of settings is rendered illusory by systematic differences in the blackening on the plates. For example, a comparison of the corresponding numbers in Table I for the east and west sides of the Sun shows a systematic excess, first on one side, then on the other. Since the mean of all the images shows an almost perfect symmetry in the two halves, the differences do not originate in the Sun, but in the plate or the photographic process. The causes which have a systematic effect on a single plate seem to affect different plates in a purely accidental manner. At least we are unable to trace any law in the differences found by comparing the east and west halves of the Sun or the values a and b.

Under these circumstances an idea of the trustworthiness of the above quantities can be gained from the differences in the nine series. These yield the mean errors given in the next to last column, which reveal the increasing uncertainty with the increase of the observed difference in brightness. The systematic enlargement of the differences in the greater part of the numerical values can be explained from the uncertainty of the scale-value a. From the deviations of the values of a given in Table III from the prescribed value we should derive, with the method of reduction employed, the mean error of the final value of $\pm 0.013\, M$ mag., where M is the difference of magnitude to be measured; and for the effect of other accidental circumstances there would remain a mean error of only ± 0.009 mag. It is probable, all things considered, that an accuracy is attained equal to that of Vogel's measures in the visible spectrum. Furthermore, the decrease in brightness is followed nearer to the limb than by previous observers. While Very's measures stopped at 0.95 and Vogel's at 0.97, there is no reason for doubting that the values obtained for $x=0.980$, 0.987, and even 0.993 are real expressions of the Sun's brightness at those distances from the center of the disk. This will scarcely apply to $x=0.997$, for at this point, in addition to the difficulties of measurement, irradiation in the film and errors in definition

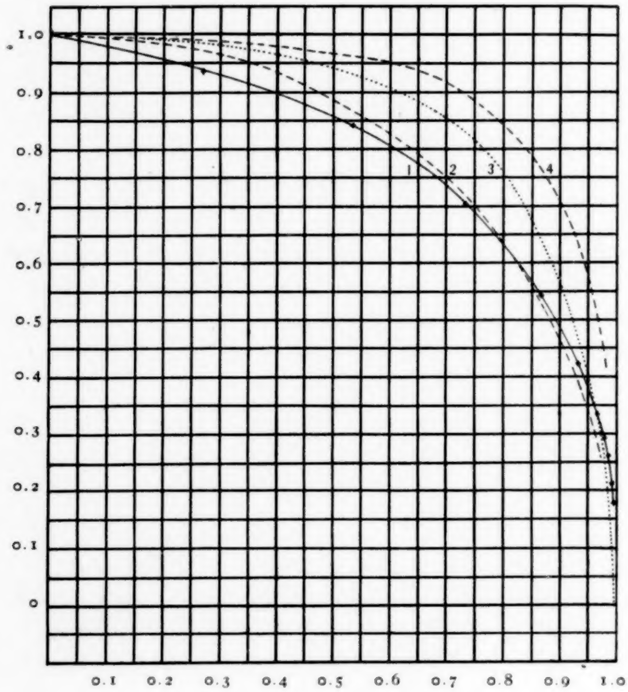
of the objective amounting to a second of arc might affect the result.

We must finally meet one more objection, that the decrease in the Sun's brightness from the center of the disk might be rendered inaccurate by the instrument itself. A simple consideration shows that the absorption in the objective and in the silver films does not change appreciably when the inclination to the axis is increased to 15′ (the Sun's radius). At first thought there would seem to be much more danger from the secondary images arising from the double reflection at the silvered surfaces. But, on the one hand, the experiments of E. Hagen and H. Rubens[1] show that the reflecting power of silver in the region solely to be considered here (from λ 315–327 $\mu\mu$) lies below 15 per cent., so that for an image arising from double reflection only 2 per cent. remains. On the other hand, we have also a direct check on this effect. A computation from the known optical constants of the objective showed that the image resulting from the reflection of the two silvered surfaces, which at the same time is the nearest of all the reflected images to the focal plane, lies 85 cm behind that plane. A halo 16 mm wide would thereby be produced around the focal image of the Sun. Its intensity at a distance of 2 mm from the Sun's limb would come out as about 0.2 of the central brightness of the real solar image, if no light was lost by reflection, and if the distribution of brightness on the Sun's disk found above is taken as our basis. Two photographs of the Sun were now made on the same plate, the objective being diaphragmed down to 10 mm and 5 mm respectively; and, moreover, a third exposure with full aperture, for which, however, the image of the Sun itself was covered up by a metal disk placed immediately in front of the plate and extending 2 mm beyond the Sun's limb. The time of exposure was in each case 10 seconds. The comparison of the opacities yielded the result that the brightness at 2 mm distance from the Sun's limb amounted to 0.0008 of the central brightness of the Sun. The brightness of the reflex image must therefore be weakened by the double reflection at least in the ratio 0.0008:0.2 or 0.004:1, and therefore cannot in fact come into consideration.

[1] *Zeitschrift für Instrumentenkunde*, **22**, 42, 1902.

IV

We will now compare the results we have obtained for $\lambda = 0.320$ with those for other wave-lengths. In the diagram the values of J/J_0 for $\lambda = 0.320$ are shown in connection with the curves obtained by Vogel for the red and violet. The noteworthy result to be derived from these curves is this: The decrease of the brightness is not



1, $\lambda = 0.322\,\mu$; 2, $\lambda = 0.409\,\mu$;
3, Earth's atmosphere; 4, $\lambda = 0.662\,\mu$.
+observed points.

more marked in the ultra-violet than in the violet; the gradual increase in the rate of falling off which is observed in passing from the red toward the violet, comes to a stop in the ultra-violet. If we were to regard as real the small difference of the curves for $\lambda = 0.320\,\mu$ and $\lambda = 0.409\,\mu$, then we should have to say that in the ultra-violet the decrease, at first stronger than in the violet, is checked on approaching the limb, and finally becomes even less than for the violet.

This behavior directly contradicts the analogy with the Earth's atmosphere, in which the absorption increases very rapidly toward the ultra-violet. This new fact should be added to that noted by Vogel: the shape of the curve does not follow the laws valid for the Earth's atmosphere. The dotted curve shows the distribution in intensity which would be found in the Earth's atmosphere viewed from without, if the surface were a self-luminous black body (calculated by doubling the Potsdam extinction table). The differing character of the decrease is noticeable, especially for the ultra-violet.

Explanation of this difference in curves can be attempted in two different ways. Seeliger[1] ascribes to the Sun's atmosphere a refractive index differing much more from unity than that possessed by the Earth's atmosphere. Schuster[2] takes into account the radiation from the Sun's atmosphere itself. The theoretical treatment of our observations with reference to such views we desire to reserve for another occasion.

We intend to continue the measures in order to obtain data as to a possible variation in the absorption of the solar atmosphere.

GÖTTINGEN AND JENA,
January 1906.

[1] *Sitzungsberichte der bayrischen Akademie der Wissenschaften*, **21**, 1891.

[2] *Astrophysical Journal*, **16**, 320, 1902.

A NEW METHOD FOR THE DISCOVERY OF ASTEROIDS

By JOEL H. METCALF

During the past four months I have put into practice a method for the photographic discovery of asteroids which has worked so well that perhaps a description of it may interest the readers of the *Astrophysical Journal.*

The old method which Professor Max Wolf has used with such wonderful success is to take a long-exposure photograph of the region to be examined, and then search the plate for trails made by the moving planets. When the asteroids are in opposition, they retrograde on an average about 34″ an hour. This on the plate of a large portrait-lens is quite an appreciable amount, and just in proportion as the objective has a longer focus, the trails become longer, and hence, other things being equal, make a fainter impression on the plate. It was on this account that the old-fashioned portrait-lens of the Petzval type was found so satisfactory. First, it gave a large field which would be important in any case; second, it gave a very short focus with great light-collecting power. So it happens that in a system of lenses of the portrait type the brilliant image would be held on the same part of the plate longer than it would have been with a lens of the same aperture, but greater focal length. As a result of this, fainter asteroids could be photographed than with the lens of longer focus.

Stars of extremely low magnitude can be photographed with very small lenses, if only the exposure time is lengthened. With asteroids, which are moving on the plate, however, if no impression is made in a given time—and that a short one—no effect will ever be produced. For illustration, in my 12-inch objective the size of the fainter star-images with an hour's exposure is 4″ to 5″. An asteroid at opposition therefore would move the diameter of a star-image in less than ten minutes. This implies that if its image is not impressed upon the plate in about ten minutes, it never will be.

It is evident, therefore, that if any method could be devised

so that the asteroids could be made stationary in reference to the plate so that longer exposures could be given, much fainter ones could be photographed. This principle has been utilized for many years in the photography of comets, and more recently Professor Bailey, of Harvard Observatory, photographed *Eros* soon after conjunction with the Sun by moving the plate to overcome the computed movement of the asteroid.

This general principle I have applied with success to the discovery of asteroids. It is just the opposite of Wolf's method, for he follows the stars so that they are points on the photographic plate and the asteroids are trails, while I have followed the asteroids and the stars are trails. This principle, which is clearly applicable to known objects, might at first sight seem to be useless for unknown objects whose movements are unknown. An inspection of the *Berliner Jahrbuch*, which gives the positions and daily motions of asteroids as they come to opposition, would, however, lead to an opposite opinion. Take for illustration the known asteroids for the first two weeks of April 1906. There are seventeen asteroids predicted to come to opposition during that time. Their average hourly motion in R. A. is —34″. The greatest motion is 41″, and the least 26″, which differ from the mean by 7″ and 8″ respectively. It is thus seen that if the photographic plate were moved 34″ an hour in the proper direction, it would follow them all within the diameter of a little over the size of a star-image and the great majority of them much more closely still. In declination the same asteroids are predicted to move on an average +10″ per hour, the greatest motion is +17″ and the least 0″. These differ from the mean 7″ and 10″, respectively. In an hour, therefore, if all the asteroids happened to fall on the same plate at the same time, they could all be followed (with the exception of one) *for an hour* within about the diameter of a star-disk. In other words, by properly moving the plate the length of effective exposure could be lengthened for them all from 10 minutes under the old method to 30 minutes, and for the majority of them to an hour or more, simply by moving the plate the amount which an average asteroid is expected to move.

In practice what I do is to place my filar micrometer on the visual

telescope, which is rigidly bound to the photographic telescope. I then obtain the east-and-west direction in the usual way by making a star follow the wire. At this point I revolve the micrometer-head in position angle, north or south as the case may be, to bring it parallel to the ecliptic, which of course is the direction of motion of the ideal mean asteroid on that date. Then I set on a star for following which is in the middle of the region I wish to examine, and the exposure begins. Every minute I turn the micrometer-head the amount of the computed mean motion and with the slow motions in right ascension and declination bring the star back to the cross-wires. This may seem to be a very tedious process, but I do not find it so. If one has to be watching the cross-wires to correct the clock and for refraction, he might as well do something else between times. Minutes almost seem like seconds when one is busy setting up the micrometer-head and bringing the star back to position.

At the end of 35 minutes' exposure, which I have found in practice sufficient to give images down to 13.5 magnitude and lower, I close the shutter of the photographic telescope and move the micrometer-wire 25″ or 30″, and then take another similar exposure of the same length. It can at once be seen that when the plates come to be developed, every star bright enough to be photographed will be represented by two trails whose length will depend upon the exposure-time, but will be equal to the amount which a mean asteroid should move in that time. Then between the trails will be the arbitrary separation given them between exposures. If there are any asteroids in the field, on the other hand—and it very rarely happens that there are none—their images will be like two points (or normal star-images) separated by the same space as the star-trails. In practice I find that the two exposures are much more satisfactory than one, as it makes it impossible to be misled by an imperfection in the film. It is the same kind of a check which Dr. Wolf accomplishes by using two telescopes and taking two plates of the same region.

The chief points of excellence which I would claim for this method are these:

First, the remarkable images which one in practice obtains—most of the asteroids come out astonishingly round and clear-cut.

FIG. 1

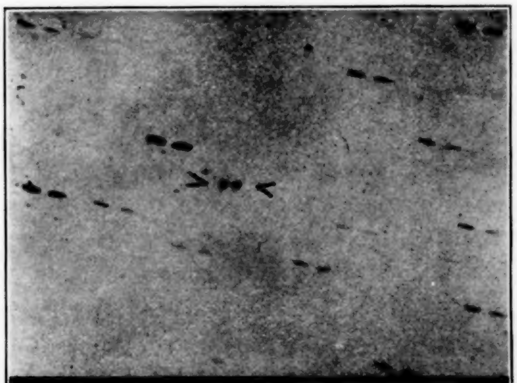
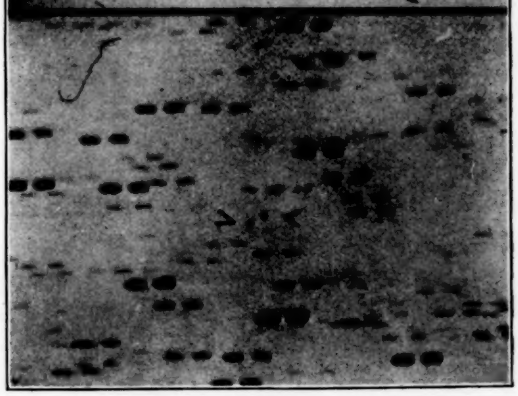


FIG. 2

FIG. 3



Photographs of Asteroids

Second, the ability to photograph very faint asteroids with a comparatively small lens. The gain over the old method in an hour's exposure must certainly be at least 2 magnitudes. In practice I have not failed to find the faintest asteroids of the *Berliner Jahrbuch.*

Third, it gives an image capable of more accurate measurement. In the old way the asteroids were usually measured by bisecting the trails on the plate, and taking that as the position at the middle time. As the trails were usually faint, slight differences of the transparency of the atmosphere between the beginning and end of the exposure would tend to shorten one end of the trail so the middle of the actual trail would not be the position of the asteroid at the middle time. Under the new method the asteroid is capable of measurement with all the accuracy of an ordinary star-image. The stars, on the other hand, are trails, but only the brighter ones could be used as reference stars for measurement, and hence slight changes of transparency of the air would not effect them. Then again any number of star-trails one pleases can be measured and a good mean position obtained.

Referring to the illustrations of this article, which are enlargements of plates taken in the way described, each pair of trails is a star, and each pair of points is an asteroid.

Fig. 1 is a bright known asteroid (17) *Thetis* of magnitude 10.6.

Fig. 2 shows a new asteroid of about the thirteenth magnitude discovered here on March 22, 1906.

Fig. 3 is 1905 *S H*, whose magnitude is 13.5. As may be seen from the plate, this asteroid was moving rapidly north (6′ per day) when the ecliptic was east and west; it is, therefore, an extreme case. Circular elements show it to have an inclination of 25° to the ecliptic. Yet it is evident that I could never have photographed it in the old way, as the extreme faintness of the short trail shows. Its motion differed widely from the mean asteroid, but it justified the method.

My attention has just been directed to the fact that in *Astronomische Nachrichten* (**144**, 331, 1897) Professor E. E. Barnard has an article on a proposed instrument for accurately photographing an unseen moving but known celestial body. In description

of it he says: "To accomplish this it is only necessary to have the guiding cross-wires attached to a light frame which can be moved by a delicate clock-work, the speed of which can be regulated to the motion of the object. This is also to be arranged so that its direction of motion can be adjusted in any position angle." He suggests the works of an ordinary watch with necessary gearing so that the speed may be regulated. "The instrument having been placed on the eye-end of the guiding telescope, it is carefully set so that the amount and direction of motion of the cross-wires shall coincide with that of the comet or minor planet." A star in the field is then followed by being kept continuously on the cross-wires by the slow motions in the usual way, but owing to the motion of the cross-wires the comet or asteroid will remain perfectly stationary on the plate.

TAUNTON, MASS.,
April 1906.

A NEW METHOD FOR DETERMINING THE RATE OF DECREASE OF THE RADIATIVE POWER FROM THE CENTER TOWARD THE LIMB OF THE SOLAR DISK

By W. H. JULIUS

The brightness of the solar disk is known to diminish considerably from the center toward the limb. Although this prominent feature of the solar phenomenon should be among the first accounted for in every theory of the Sun, it leads to problems presenting so many difficulties that a satisfactory explanation is, until now, altogether wanting. And even the empirical study of the law according to which the radiating power varies across the disk is not very advanced.

What we know about the question is founded on researches in which either a photometer or a thermopile, a bolometer or a radio-micrometer, was used for exploring an *image* of the Sun. The results obtained by different observers are rather discordant.[1] This may be partly due to instrumental or accidental errors, but there is also a systematic error which must have influenced similarly all of the results thus obtained, and which proceeds from the scattering of the rays by the terrestrial atmosphere. In any point of an image of the Sun is not only to be found the radiation coming from the corresponding point of the disk, but, in addition, some diffused radiation proceeding from other parts of the disk. This disturbing effect will, of course, vary in magnitude with the condition of the atmosphere, but it will always act in a leveling way, parts of the image lying near the edge receiving more diffused radiation from the middle parts of the disk than the central parts of the image receive from the edge parts of the disk.

We may completely avoid this source of error by using a method in which the radiating power of the different parts of the disk is calculated from observations made on the occasion of a total eclipse of the Sun.

[1] Cf. J. Scheiner, *Strahlung und Temperatur der Sonne*, pp. 43–49, 1899.

Let us suppose the curve representing the intensity of the solar radiation from the first until the fourth contact as a function of time, to be exactly known.[1] The curve will show us by how much the total radiation has increased or decreased between any two epochs. Every (positive or negative) increment is exclusively due to rays coming from that strip of the solar disk through which the Moon's limb has appeared to move between just those epochs.

Suppose the time after third contact to be divided into equal intervals of, say, two minutes, and the position of the Moon's limb at the end of each interval delineated on the solar disk, then the latter will be divided into thirty-nine narrow strips, successively contributing the *known* quantities a, b, c, d . . . . to the total radiation.

Now, let us distinguish n concentric zones on the solar disk and denote by $x_\alpha, x_\beta, \ldots . x_\nu$ the radiation coming from these zones per unit surface. (In accordance with the results obtained by Langley and by Frost, we shall suppose the radiating power to vary only with the distance from the center, not with the position angle.) One of the strips will contribute to the radiation

$$d=\delta_1 x_\alpha+\delta_2 x_\beta+\ldots . \delta_n x_\nu$$

if it cuts out of the first zone an area δ_1, out of the second zone an area δ_2, etc. The next strip contributes:

$$e=\epsilon_1 x_\alpha+\epsilon_2 x_\beta+\ldots . \epsilon_n x_\nu$$

and so on. We get thirty-nine equations from which $x_\alpha, x_\beta, \ldots$ x_ν may be resolved.

DETERMINATION OF THE COEFFICIENTS OF THE n UNKNOWN QUANTITIES

I have found the coefficients $\delta_1, \delta_2, \ldots . \epsilon_1, \epsilon_2,$ by . . . . weighing. On a piece of excellent homogeneous paper the solar disk was drawn and divided into a suitable number of concentric zones, which were intersected by arcs representing the Moon's limb in its successive positions. The following astronomical data,

[1] It is well known that, at Burgos, the observation of the eclipse of August 30, 1905, was not favored by a clear sky. (Cf. the Preliminary Report in the *Proceedings Royal Acad. Amsterdam*, **8**, 501, 1905.) Nevertheless, the measurements of total radiation have yielded some results of sufficient accuracy to justify in our present investigation, the use of the radiation-curve then secured. Further particulars regarding the observations will soon be published in the complete report on our expedition.

necessary for making the drawing, have been kindly procured for me by Professor A. A. Nyland.

Contact	I	II	III	IV
Position angle	293°.4	104°.5	304°.9	114°.9
Local time	$23^h\ 33^m\ 10^s$	$0^h\ 51^m\ 58^s$	$0^h\ 55^m\ 39^s$	$2^h\ 12^m\ 14^s$

Moon's radius: Sun's radius = 132.8 : 126.8.

Now the strips were carefully separated from each other and weighed (for subsequent control). Then each strip was cut along the zone-circles, and the pieces were weighed separately. In order to make the pieces recognizable, the zones had all been differently painted, each with a narrow line of water-color. The weighings, which were accurate to half a milligram, gave the coefficients of the unknown quantities x_α, x_β . . . . x_ν. So the unit of area, adopted for measuring the surface of the solar disk, corresponds to a piece of our drawing-paper weighing 1 milligram.

The breadth of each of the outer five concentric zones was 1/20 of the Sun's radius; then came seven zones with breadth 1/10 of the radius, each leaving around the center a circle with radius 1/20. The average distances of the zones from the center, expressed in thousandth parts of the radius, will now be used as indices α, β, ... of our thirteen unknown quantities; so these will be written:

$$x_{975},\ x_{925},\ x_{875},\ x_{825},\ x_{775},\ x_{700},\ x_{600},\ x_{500},\ x_{400},\ x_{300},\ x_{200},\ x_{100},\ x_0\ .$$

On p. 316 the equations are written out. We have confined ourselves to thirteen equations; increasing this number would not have led to greater accuracy, as the values of a, b, c, . . . had to be found from the radiation-curve—that is, by graphical interpolation—in which process it is understood that *all* of the observations have already been taken into consideration.

DETERMINATION OF THE CONSTANT TERMS OF THE EQUATIONS

Table I contains the results of the observations made at Burgos with our actinometer. The second column gives the galvanometer deflections, from which are calculated the numbers of the

TABLE I

Time	Galvanometer Deflections	Intensity of Radiation	Time	Galvanometer Deflections	Intensity of Radiation
22h 28m 48s	280.0	1,750,000	0h 20m 48s	128.5	819,000
36 0	231.0	1,444,000	2d contact 51 58		
38 33	287.0	1,794,000	53 53	3.0	9
			54 28	13.0	13
46 58	287.0	1,794,000	55 18	33.0	33
51 38	270.0	1,688.000	3d contact 55 40		
53 49	260.5	1,631,000	55 58	600.0?	600?
56 8	278.5	1,745,000	57 58	118.5	23,000
			58 33	98.5	19,100
23 4 58	256.0	1,610,000	59 13	219.5	42,700
8 3	283.5	1,786,000	59 53	286.0	55,700
9 56	284.5	1,792,000	1 1 18	232.5	74,800
11 44	275.0	1,736,000	2 28	170.0	108,800
1st contact 33 8			3 3	152.5	97,700
35 48	226.0	1,430,000			
38 3	256.5	1,625,000	7 38	323.5	207,000
40 38	269.5	1,709,000			
41 38	270.0	1,712,000	21 15	331.5	635,000
42 48	270.5	1,715,000	22 3	347.5	665,000
44 0	260.0	1,649,000	23 3	151.5	676,000
45 33	259.5	1,646,000	23 58	162.0	722,000
46 38	256.5	1,627,000	24 53	167.0	745,000
47 52	248.5	1,566,000	25 53	174.0	776,000
48 53	250.5	1,589,000	26 53	180.5	805,000
50 8	249.0	1,580,000	27 53	186.5	832,000
51 33	241.0	1,529,000	28 58	194.0	865,000
53 8	233.5	1,483,000	30 8	201.0	897,000
55 3	227.0	1,442,000	31 8	207.5	926,000
56 33	226.0	1,435,000	32 11	213.0	950,000
50 23	216.5	1,376,000	33 13	220.0	981,000
			34 20	225.5	1,007,000
0 7 23	192.0	1,222,000	35 25	232.5	1,037,000
8 53	184.0	1,170,000	36 34	237.5	1,060,000
10 28	177.0	1,127,000			
11 43	171.5	1,091,000	2 1 58	338.0	1,506,000
13 13	165.5	1,054,000	3 8	248.0	1,581,000
14 58	159.0	1,013,000	4th contact 12 24		
17 3	150.0	956,000	13 18	258.5	1,648,000
19 28	136.0	867,000	14 20	260.0	1,657,000

third column, representing the intensity of the radiation.[1] Owing to the clouds, there are large gaps in the series of observations but

[1] Particulars concerning the connection between the numbers of these two columns will be found in the forthcoming report on the Dutch expedition. The method and the instruments used at Burgos were the same that are described in "Total Eclipse of the Sun, May 18, 1901: Reports on the Dutch Expedition to Karang Sago, Sumatra; No. 4: Heat Radiation of the Sun during the Eclipse," by W. H. Julius. The numbers of the third column are proportional to the total radiation coming from a circular patch of the sky, 3° in diameter, with the Sun in its center.

nevertheless, after the results had been plotted, we saw that there was only little room left for fancy when drawing the radiation-curve in such a way that closest agreement with the observational data was obtained. As a matter of course, the curve has not been drawn *between the series of points, but so as to join the highest points,* for the observed values could only be too small. Only one exception is made to this rule, the value found at $0^h\ 17^m\ 3^s$ being very probably too high by some error or instrumental disturbance.

$a = 126\ x_{975}$
$b = 66x_{975} + 101x_{925}$
$c = 28x_{975} + 59x_{925} + 84x_{875} + 1x_{825}$
$d = 18x_{975} + 29x_{925} + 50.5x_{875} + 77x_{825} + 1.5x_{775}$
$e = 13x_{975} + 19x_{925} + 27.5x_{875} + 46x_{825} + 69.5x_{775} + 2x_{700}$
$f = 10x_{975} + 14x_{925} + 19x_{875} + 28x_{825} + 40x_{775} + 66x_{700}$
$g =$
$h = 8x_{975} + 10x_{925} + 12x_{875} + 15x_{825} + 18x_{775} + 57x_{700} + 58x_{600}$
$i =$
$j = 7x_{975} + 8x_{925} + 9x_{875} + 10.5x_{825} + 12.5x_{775} + 30x_{700} + 48x_{600} + 51x_{500}$
$k =$
$l = 6x_{975} + 6.5x_{925} + 7x_{875} + 8x_{825} + 9x_{775} + 23x_{700} + 28.5x_{600} + 40x_{500} +$
$45x_{400}$
$m =$
$n = 5.5x_{975} + 6x_{925} + 7x_{875} + 8x_{825} + 8x_{775} + 19x_{700} + 21x_{600} + 25x_{500} +$
$33x_{400} + 36x_{300}$
$o =$
$p = 5.5x_{975} + 6x_{925} + 6.5x_{875} + 7x_{825} + 7x_{775} + 16x_{700} + 17.5x_{600} + 19.5x_{500}$
$+ 22.5x_{400} + 26.5x_{300} + 31x_{200}$
$q =$
$r = 5.5\ x_{975} + 6x_{925} + 6.5x_{875} + 7x_{825} + 7x_{775} + 15.5x_{700} + 16.5x_{600} +$
$17.5x_{500} + 18.5x_{400} + 18.5x_{300} + 21.5x_{200} + 20.5x_{100}$
$s =$
$t = 5.5x_{975} + 6x_{925} + 6.5x_{875} + 7x_{825} + 7x_{775} + 15x_{700} + 15.5x_{600} + 16.5x_{500} +$
$17x_{400} + 17.5x_{300} + 18x_{200} + 19x_{100} + 8x_0$

The central part of the radiation-curve has been reproduced on the annexed figure. For determining *a*, *b*, *c*, ... we have used the part included between $0^h\ 55^m$ and $1^h\ 37^m$, which was very carefully constructed on a larger scale. It deserves notice that the relative accuracy of the small ordinates (corresponding to few

minutes after totality) is nearly as great as that of the larger ones, because the galvanometer deflections from which they were calculated are all lying between 118 and 347 scale-divisions.

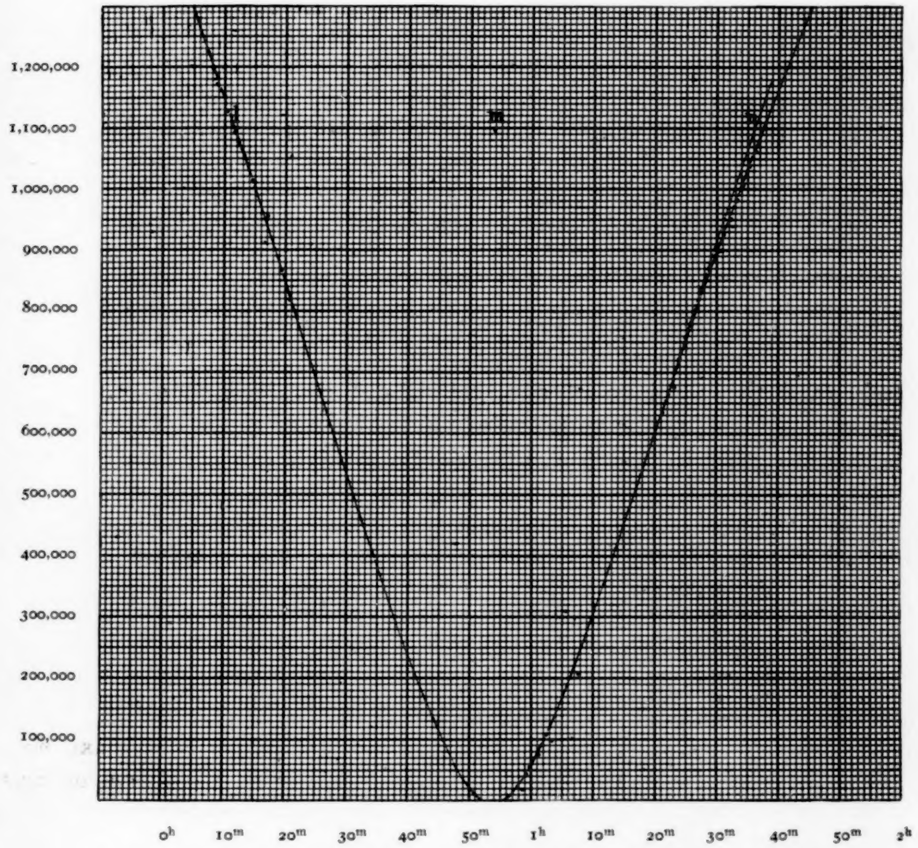


FIG. 1.—Central portion of the radiation-curve obtained during the solar eclipse of August 30, 1905.

Table II refers to this part of the radiation-curve. In the second column are given the ordinates of the curve at the epochs $0^h\ 55^m\ 40^s$ and every two minutes later; the unit corresponds to an intensity $=1000$. But this observational curve has to be corrected, owing to the circumstance that in the lapse of time considered the Sun's altitude has diminished. We may proceed as follows. Apart

TABLE II

Time	Ordinates of Radiation Curve	Ordinates of Corrected Radiation Curve	Increments	Time	Ordinates of Radiation Curve	Ordinates of Corrected Radiation Curve	Increments
0^h 55^m 40^s	0	0		17^m 40^s	532.0	535.0	61.0 = *k*
57 40	20.1	20.1	20.1 = *a*	19 40	594.0	597.0	62.0 = *l*
59 40	52.5	52.5	32.4 = *b*	21 40	655.0	659.0	62.0 = *m*
1 1 40	91.0	91.0	38.5 = *c*	23 40	717.0	721.0	62.0 = *n*
3 40	136.5	136.5	45.5 = *d*	25 40	776.0	783.0	62.0 = *o*
5 40	187.0	187.0	50.5 = *e*	27 40	834.5	844.5	61.5 = *p*
7 40	240.0	241.0	54.0 = *f*	29 40	891.5	905.5	61.0 = *q*
9 40	296.0	297.0	56.0 = *g*	31 40	947.0	966.0	60.5 = *r*
11 40	354.0	355.0	58.0 = *h*	33 40	1001.0	1026.0	60.0 = *s*
13 40	412.0	414.0	59.0 = *i*	35 40	1053.5	1085.5	59.5 = *t*
15 40	472.0	474.0	60.0 = *j*				

from a possible influence of sun-spots or faculæ, there is no reason why the eclipse-curve would not be symmetrical if the Sun's altitude (and the condition of our atmosphere) remained constant. Between 23^h and 1^h the variation of altitude is very small. Now, taking $0^h\ 53^m\ 50^s$ as the epoch of mid-eclipse, we draw a horizontal

TABLE III

RADIATION PER UNIT SURFACE OF THE CONCENTRIC ZONES OF THE SOLAR DISK

$x_{975} = 0.1595$	$x_{500} = 0.3843$
$x_{925} = 0.2166$	$x_{400} = 0.4153$
$x_{875} = 0.2501$	$x_{300} = 0.4278$
$x_{825} = 0.3023$	$x_{200} = 0.4240$
$x_{775} = 0.3290$	$x_{100} = 0.4380$
$x_{700} = 0.3488$	$x_0 = 0.4388$
$x_{600} = 0.3662$	

line through a point *m* corresponding to that epoch. The line cuts the descending branch of the curve in *l;* we make $mn = ml$ and thus find a point *n* of the hypothetical radiation-curve for constant altitude of the Sun. Acting in a similar way for a few more points, we get an idea of the magnitude of the smoothly increasing correction which is to be applied to the ordinates of the ascending branch. K. Ångström's measures of the intensity of the radiation for different altitudes of the Sun[1] have also been considered in determining the correction. The third column of Table II con-

[1] K. Ångström, "Intensité de la radiation solaire à différentes altitudes: Recherches faites à Ténériffe 1895 et 1896."

tains the ordinates of the corrected curve; in the fourth column are given their successive increments which, of course, are the values to be assigned to the absolute terms of our equations.

RESULTS

The solution of the equations leads to the numbers of Table III; the results are plotted in Fig. 2 on the plate. Through these points we have drawn a curve satisfying the condition that its curvature should gradually diminish; it shows us the law of variation of the

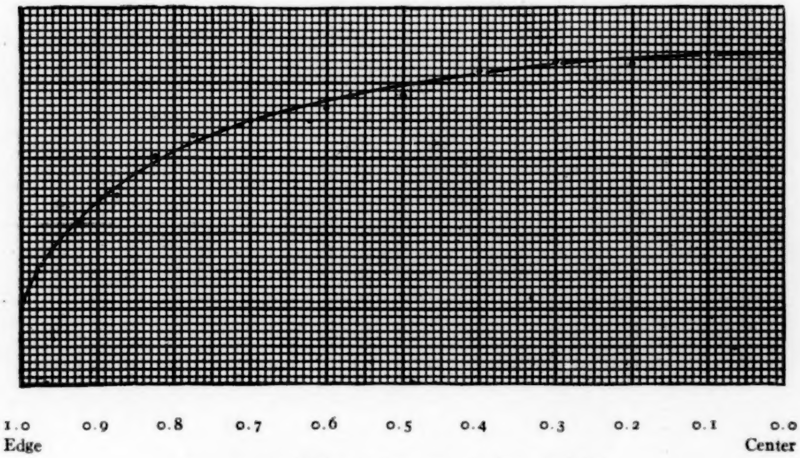


FIG. 2.—Radiating Power across the solar disk.

radiating power from the edge toward the center of the solar disk. Putting the ordinate at the center equal to 100, and expressing the other ordinates in the same unit, we get numbers comparable with the results obtained by other investigators.

The comparison with the spectro-photometric observations by H. C. Vogel,[1] and with the measurements of total radiation made with a radio-micrometer by W. E. Wilson[2] and with a thermopile by E. B. Frost,[3] is given in Table IV. We add in Table V the results of a spectro-bolometric investigation by Very,[4] as these

[1] *Ber. der Berl. Akad.*, 1877, p. 104.

[2] *Proc. Roy. Irish Acad.* [3], **2**, 299, 1892.

[3] *Astronomische Nachrichten*, **130**, 129, 1892.

[4] *Astrophysical Journal*, **16**, 73, 1902.

numbers have been used by F. W. Very and by A. Schuster[1] in testing their explanations of the phenomenon.

According to Frost's measurements, the total radiation appears to diminish from the center to the limb in about the same proportion as the radiation of wave-length 650 $\mu\mu$, whereas my numbers show a decrease very similar to that exhibited by rays of wave-length 510 $\mu\mu$. At first sight the evidence is in favor of the results obtained by Frost, because the maximum of the curve representing the energy in the solar spectrum (or perhaps rather the "center of gravity" of the inclosed surface) lies closer to 650 $\mu\mu$ than to 510 $\mu\mu$. But this argument fails; for the measurements of Vogel and those of Frost are all disturbed alike by atmospheric diffusion. Had the

TABLE IV

Distance from Center of Disk	H. C. Vogel's Spectro-Photometric Measurements						Total Radiation		
	405–412 $\mu\mu$	440–446 $\mu\mu$	467–473 $\mu\mu$	510–515 $\mu\mu$	573–585 $\mu\mu$	658–666 $\mu\mu$	Receiver in Solar Image: Wilson	Receiver in Solar Image: Frost	Eclipse-Curve Julius
0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
0.1	99.6	99.7	99.7	99.7	99.8	99.9	99.9	99.9	99.8
0.2	98.5	98.7	98.8	98.7	99.2	99.5	99.6	99.4	98.6
0.3	96.3	96.8	97.2	96.9	98.2	98.9	98.8	98.4	96.6
0.4	93.4	94.1	94.7	94.3	96.7	98.0	97.3	96.3	94.0
0.5	88.7	90.2	91.3	90.7	94.5	96.7	95.3	93.6	90.3
0.6	82.4	84.9	87.0	86.2	90.9	94.8	92.5	89.8	85.5
0.7	74.4	77.8	80.8	80.0	84.5	91.0	88.7	84.6	79.5
0.75	69.4	73.0	76.7	75.9	80.1	88.1			75.3
0.8	63.7	67.0	71.7	70.9	74.6	84.3	83.9	77.9	70.1
0.85	56.7	59.6	65.5	64.7	67.7	79.0			63.5
0.9	47.7	50.2	57.6	56.6	59.0	71.0	74.9	68.0	55.0
0.95	34.7	35.0	45.6	44.0	46.0	58.0		(60.5)	44.0
1.0	13.0	14.0	16.0	16.0	25.0	30.0	45.1		(24.0)

TABLE V

Distance from Center	F. W. Very's Spectro-Bolometric Measurements						
	416 $\mu\mu$	468 $\mu\mu$	550 $\mu\mu$	615 $\mu\mu$	781 $\mu\mu$	1010 $\mu\mu$	1500 $\mu\mu$
0.5	85.8	90.2	93.3	94.8	94.1	94.3	95.9
0.75	74.4	76.4	83.1	84.5	88.5	89.4	95.0
0.95	47.1	46.2	58.7	68.1	74.9	76.5	85.6

[1] *Astrophysical Journal*, **16**, 320, 1902; **21**, 258, 1905.

spectro-photometric observations been free from this influence, then the rate of decrease of the radiation from the center toward the limb would doubtless have been found quicker for all wave-lengths, and, very probably, the distribution for the region 650 $\mu\mu$ would have proved to agree better with my results than with the uncorrected values of Frost.

Wilson's measurements seem to have been affected by still other causes of error than atmospheric scattering, as his numbers are greater than those obtained by Frost, and do not harmonize as well as the latter's with the spectro-photometric series.

The observations of Very have given considerably greater ratios in the marginal regions than those of Vogel. Mr. Very himself points out the difference, and remarks that the bolometer has an advantage over the eye in the red where the heat is great; but I may suggest, on the other hand, that instrumental errors (reflection or scattering of light by prisms, lenses, tubes, etc.) are more easily discovered and corrected in spectro-photometric than in spectro-bolometric work.

It seems to me that observing an eclipse-curve by means of a very simple but sensitive actinometer, without lenses or mirrors, must yield results concerning the radiation of different parts of the solar disk which deserve more confidence than the values hitherto obtained in other ways. I wish to lay stress upon the advantages of our ***method***, rather than on the reliability of the numbers secured at Burgos under not very favorable circumstances. In a clear sky the shape of the eclipse-curve will easily be found with very great accuracy.

The same method will also be applicable with radiations covering limited parts of the spectrum, if we only put suitable ray-filters before the opening of one of the diaphragms in the actinometer. It may even be possible, in a future eclipse, to use an arrangement which brings several ray-filters by turns before the opening; thus, when employing a quick galvanometer, one would be able to simultaneously determine, with one actinometer, the eclipse-curves for rays belonging to five or more regions of the spectrum, and the results would be independent of selective atmospheric scattering.

REMARKS ON THE HYPOTHESES USED FOR EXPLAINING THE DISTRIBUTION OF THE RADIATING POWER ON THE SOLAR DISK

The diminution of the intensity of radiation toward the limb is almost generally ascribed to absorption of the rays by the solar atmosphere,[1] and it is supposed that, in the absence of that atmosphere, the photosphere would show itself as an equally luminous disk. But then it appears to be impossible to find such values for the thickness of that atmosphere and for its coefficient of absorption as to give a law for the rate of diminution of brightness, consistent with observation. Very, for instance (*loc. cit.*), when attributing the effect to absorption only, arrives at the absurd result that the marginal measures indicate a more highly transmissive atmosphere than those measures nearer the center. He therefore suggests the existence of other influences which, combining with the absorbent process, would reconcile theory to observed facts. Diffraction by fine particles, columnar structure of the solar atmosphere, irregularity of the photospheric surface, are thus introduced.

Schuster (*loc. cit.*), on the other hand, is of opinion that the difficulty which has been felt in explaining the law of variation of intensity across the solar disk is easily removed by placing the absorbing layer sufficiently near the photosphere and taking account of the radiation which this layer, owing to its high temperature, must itself emit. He then really finds values for the absorption and the emission of that layer, harmonizing with the results of Very's and Wilson's[2] measurements, and also with the properties of the energy-curve of the spectrum of a black body at different temperatures. But, for all that, serious doubts as to the correctness of the premise and the conclusions must remain.

Indeed the calculations of Schuster as well as those of Very, Wilson, Langley, Pickering, and others, concerning the same subject, are based on the assumption that the light travels along straight lines through the solar gases, whereas everyone who has duly noticed A. Schmidt's *Strahlenbrechung auf der Sonne* will at the least have to admit that rays coming from the outer zones of the disk must have followed curved paths through the solar atmosphere. From this circumstance the said calculations lose their convincing power.

[1] J. Scheiner goes as far as to say: "Eine andere Deutung des Lichtabfalls ist nicht zulässig" (*Strahlung und Temperatur der Sonne*, p. 40).

[2] W. E. Wilson and A. A. Rambaut, *Proc. Roy. Irish Acad.* [3], **2**, 299–334, 1892.

And, besides, the fundamental idea that a considerable portion of the photospheric radiation should be absorbed by a thin atmosphere encounters a difficulty of greater importance still. This point, I think, has also first been raised by Schmidt. What becomes of the absorbed energy accumulating in the atmosphere? According to Schuster, e. g. (*loc. cit.*, p. 322), the atmosphere transmits largely one-third of the radiation emitted by the photosphere; so it stops almost two-thirds and only a small fraction of this absorbed energy leaves the Sun in the form of radiation emitted by the atmosphere itself. After all, more than half of the radiation coming from the photosphere is retained by the absorbing layer, and we cannot suppose it to go back to the interior without violating the second law of thermodynamics. As long as it has not been shown how the solar atmosphere may get rid of that immense quantity of energy continually supplied and never radiated, similar considerations will remain very unsatisfactory.

Our problem appears to be much less intricate when viewed from the standpoint taken by Schmidt,[1] though the mathematical treatment will not be easy. A uniformly luminous sphere surrounded by a concentric, perfectly transparent refracting envelope, will offer the aspect of a disk the brightness of which diminishes toward the limb. This has been stated approximately by Schmidt for the case of a homogeneous, sharply limited envelope. It is easily understood that a similar result must be obtained when a transparent atmosphere of gradually decreasing density and refractive power is assumed; but then, of course, the rate at which the luminosity varies on the disk will depend on the law of density-variation. We may proceed a little farther, and accept Schmidt's hypothesis that the incandescent core of the Sun is *not* a sphere with a sharp boundary, but a gaseous body the density and radiating power of which are smoothly diminishing along the radius. In this way, I think, we dispose of premises from which it seems possible to derive an explanation of the general aspect of the solar disk without involving such serious difficulties as were hitherto encountered.

UTRECHT,
February 1906.

[1] A. Schmidt, *Physikalishe Zeitschrift*, **4**, 282, 341, 453, 476; **5**, 67, 528. (1903 and 1904.)

THE SPECTRA OF SULPHUR DIOXIDE

By FRANCES LOWATER

I. THE ABSORPTION SPECTRUM

I. HISTORY

The absorption spectrum of sulphur dioxide was investigated in the ultraviolet region by W. A. Miller[1] in 1863. He inclosed the gas in a previously exhausted brass tube, two feet in length, the ends being closed by quartz plates. His source of radiation was the silver spark. He found that the silver spectrum was transmitted from scale-reading 96.5 to 110.5, at which point it was abruptly cut off. Estimated from a curve plotted from his maps, this range appears to be from λ 420 to 345 $\mu\mu$. He does not say at what pressure the gas was inclosed in the tube.

In 1883 Professors Liveing and Dewar[2] found that sulphur dioxide produced an absorption band "very marked between R (3179) and wave-length 2630, and a fainter absorption extending on the less refrangible side to O(3440), and on the other side to the end of the range photographed, wave-length 2300." They used as source of light the iron spark, and obtained the spectrum by means of a spectrometer having a single quartz prism and quartz lenses.

The present investigation was undertaken at the suggestion of Professor J. S. Ames, of Johns Hopkins University, and carried out at Bryn Mawr College.

II. APPARATUS AND METHOD

For the greater part of the work the gas was inclosed in a steel tube, 207 cm long, having its ends closed with quartz plates. It was provided with two pin valves for exhaustion of the tube and admission of the gas. The spectral apparatus was a quartz spectrograph of middle size by Fuess, used with a Rowland plane reflection grating having 14,438 lines to the inch.

[1] *Phil. Trans.*, **152**, II, 861–887, 1863.

[2] *Proc.. R. S*, **35**, 71–74, 1883.

In the region λ 690 to 390 $\mu\mu$ the carbon arc was used as source of light. In the region λ 410 to 210 $\mu\mu$ the source of light was the spark of an alloy of cadmium and zinc in proportions of their atomic weights. The beam was made parallel by a quartz lens before it entered the tube; on emergence it was brought, by another quartz lens, to a focus on the slit of the spectrograph. To obtain a continuous background with this spark, since no alternating current was available, the current from ten secondary cells was supplied to the primary of a ten-inch induction coil, and a capacity of 0.03 mfd. was placed across the terminals of the secondary, in parallel with the spark.

Before use the steel tube was thoroughly cleaned with hot potassium hydroxide and distilled water, and then thoroughly dried. The tube was exhausted by a water aspirator to about 1½ cm pressure, filled with sulphur dioxide to a pressure greater than one atmosphere, and again exhausted; after this process had been repeated several times, the tube was filled with sulphur dioxide to the desired pressure. The sulphur dioxide was obtained from liquid sulphur dioxide; the high temperature of liquefaction (—10° C.) of this gas insures its purity from other gases except air, which may be present in the gas above the liquid. Before using any of the gas a considerable quantity was allowed to escape to insure that the following supply of gas should be free from air. Before admission into the tube, the sulphur dioxide was passed through a tube containing phosphorus pentoxide to insure its dryness.

The photographic plates used were Seed's No. 27 Gilt Edge. An exposure of two hours was given for the absorption spectrum in every case. A comparison spectrum was photographed on the same plate as the absorption spectrum immediately above or below the latter.

Standard wave-lengths were obtained from the lines of *Cd*, *Zn*, *Pb*, and *Fe*, which were transmitted in sufficient numbers in the absorption spectrum, the *Pb* and *Fe* being present as impurities; by this means errors were avoided that might arise from disturbance of the apparatus in changing from the arrangement for the absorption spectrum to that for the comparison or another standard spectrum.

The absorption spectrum of sulphur dioxide in the violet and ultra-violet regions was found for pressures of three atmospheres, two atmospheres, and one atmosphere, $1\frac{1}{2}$ cm, 0.45 cm, and 0.13 cm. The wave-lengths were determined by measurements made on the photographic plates in the usual way. The dividing engine used for this purpose was one by Gaertner, on which readings could be made to 0.0001 mm; that is, to a greater accuracy than settings could be made on the bands. The reduction factor was roughly 32 tenth-meters to 1 mm.

III. RESULTS

In the region λ 690 to 390 $\mu\mu$ no absorption bands are found. In the region λ 410 to 210 $\mu\mu$ the photographs show that the absorption spectrum, except at very low pressures of the gas, consists of one very wide band and a number of comparatively narrow bands of different widths and intensities. Tables I and II give the wave-lengths and intensities of the bands. The intensities are estimated by eye from the photographic plates; the scale is from 10 to $\frac{1}{2}$, 10 being the maximum and applied to bands at whose center of gravity none of the continuous background is transmitted. In many cases it is difficult to obtain accurate values of the wave-lengths; in some cases this is due to the width of the band—e. g., 3, 8, or 11 tenth-meters, while in other cases it is due to the presence of a metal line which falls within the absorption band and is strong enough to be transmitted when the continuous background is absorbed. This limitation in accuracy is apparent on comparing the readings for the same line as given in parallel columns in the tables which follow.

A tube filled with oxygen at one atmosphere's pressure and sulphur dioxide at one atmosphere's pressure gave the same spectrum as the tube filled with sulphur dioxide only at one atmosphere's pressure.

In the tables, s. denotes sharp, b. broad, n. narrow, h. hazy, i.d. ill defined, and v. very.

TABLE I

ABSORPTION SPECTRUM OF SULPHUR DIOXIDE AT DIFFERENT ATMOSPHERIC PRESSURES

λ for 3 Atmos. Pressure	Intensity and Character	λ for 2 Atmos. Pressure	Intensity and Character	λ for 1 Atmos. Pressure	Intensity and Character
3881.7	9b.	3881.5	6	3881.8	1
3878.4	2s.	3878.7	3	3878.8	1n.
3828.3	10b.	3828.5	6	3828.5	2
		3825.3	3	3825.2	1n.
3776.3	3	3776.3	2	3776.4	½
3750.6	10b.	3751.1	8	3751.0	3b.
		3747.0	5s.	3747.0	2
3701.9	10v.b.	3701.7	10b.	3701.3	5s.
				3698.9	2n.
3657.4	2s.	3657.5	3n.	3657.6	1
3654.4	1	3654.4	3	3654.1	1
3650.6	1s.	3650.6	3n.	3650.7	1
3635.4	4b.	3635.4	4b.	3636.2	1b.
		3628.4	1		
		3623.5	2		
3593.9	4b.	3594.2	4v.b.	3594.2	1
3579.0	8b.	3579.1	5b.	3579.2	2
3532.8	9b.	3532.4	5b.	3532.5	1
		3529.6	3n.	3529.6	½
		3522.2	1		
		3512.3	½		
3509	f.b.	3510.1	1		
		3507.2	1		
3504	f.n.	3503.5	½		
3494.2	1	3494.1	1		
3490.1	1	3490.2	1		
3486.8	1	3486.2	½		
3474.7	1s.	3474.8	½		
3442.6	4b.	3443.2	4b.	3443.2	1
3434.1	1	3435.1	2		
3431.7	1	3432.2	2		
3423.9	2				
3422.6	3	3422.1	1		
3421.2	5	3421.3	2		
3418.7	5	3418.7	2		
3416.8	3	3417.1	2		
3414.3	2				
3412.4	2				
		3406.9	½		
3401.2	2				
3399.8	2				
3398.4	5	3398.3	1i.d.		
		3395.9	5i.d.		
3394.8	8				
		3393.9	4i.d.		
3392.5	6	3392.0	4i.d.		
		3389.3	4		
3386.7	7	3387.0	5		
3380	beginning of wide band	3384.7	4		
		3378.0	8		

TABLE I—*Continued*

λ for 3 Atmos. Pressure	Intensity and Character	λ for 2 Atmos. Pressure	Intensity and Character	λ for 1 Atmos. Pressure	Intensity and Character
		3375.9	9		
		3372.0	9	3372.1	2s.
		3365.9	9	3364.1	4s.
		3358.4	9	3358.7	8s.
		3351	beginning of wide band	3350.8	4s.
				3338.4	7
				3333.4	10
				3330	beginning of wide band

TABLE II

ABSORPTION SPECTRUM OF SULPHUR DIOXIDE AT LOW PRESSURES.

LENGTH OF COLUMN OF GAS = 207 CM				LENGTH OF COLUMN OF GAS = 20 CM	
λ for 1½cm. pressure	Intensity and Character	λ for 0.13 cm. Pressure	Intensity and Character	λ for 1.35 cm. Pressure	Intensity and Character
3226.2	2				
3211.4	1				
3207.6	1				
3203.4	1				
3198.3	3				
3195.4	4				
3190.3	1				
3187.1	1			3178.6	f.
3180.6	9	3180.7	2		
3171.5	8 n.h.				
3166.2	8 n.h.				
3157.5	10 h.				
3152.7	10 h.	3151.9	2		
		3149.8	½s.	3150.0	½
		3147.8	½s.		
3146.6	10 h.	3145.3	½		
		3143.1	½s.		
		3137.7	½		
3134	beginning of wide band	3131.0	5n.		
		3128.7	2s.	3129.3	1
		3125.7	2s.	3124.6	1
		3120.3	4n.		
		3111.3	5s.		
		3105.8	7	3104.7	6
		3101.4	4s.		
				3093.2	1s.
				3089.7	1s.
		3086.0	10	3086.2	8s.
				3084.2	2s.
				3082.4	2s.

TABLE II.—*Continued*

Length of Column of Gas=207 cm				Length of Column of Gas=20 cm	
λ for 1½ cm Pressure	Intensity and Character	λ for 0.13 cm Pressure	Intensity and Character	λ for 1.35 cm Pressure	Intensity and Character
		3064.9	10	3063.4	9
		3043.9	10	3042.6	9
		3022.6	10	3021.7	10
		3003.6	10 i.d.	3001.4	10
		2988	10 i.d.		
				2981.5	10
		2978	10 i.d.		
		2968	beginning of wide band	2962.0	10
				2943.0	10
				2927.	beginning of wide band
		2715.3	end of wide band		
		2701.5	9	2700.3	end of wide band
		2693.5	7	2692.3	9 i.d.
		2684.8	9	2683.7	10
		2676.7	7	2676.3	10
		2669.5	9	2668.6	10
		2660.1	8	2659.4	10
		2654.9	7	2653.2	9
		2653.3	7		
		2647 1	8	2646.6	9
		2643.0	7	2642.9	8
		2638.0	8	2637.3	9
		2633.0	7n.	2632.7	8
		2627.5	5	2627.1	7
		2623.1	5		
		2620.9	5	2621.2	8
		2616.9	5		
		2615.4	5		
		2613.7	7s.	2613.8	7
		2611.4	4		
		2596.8	5	2596.2	5
		2591.4	4	2590.8	3
		2585.2	3		
				2583.5	4
		2582.7	3		
		2512.2	3		
		2495.9	4	2496.2	2
		2478.1	3	2477.6	1
		2471.6	3	2471.4	1
2467	end of wide band				
		2464.3	2		
2456.	9 i.d.	2454.1	7	2454.5	2
		2448.3	6	2447.9	1

TABLE II.—*Continued*

Length of Column of Gas = 207 cm				Length of Column of Gas = 20 cm	
λ for $1\frac{1}{2}$ cm Pressure	Intensity and Character	λ for 0.13 cm Pressure	Intensity and Character	λ for 1.35 cm Pressure	Intensity and Character
2439	9 v.i.d.				
		2433.1	3		
2415.5	9 i.d.				
2401	9 i.d.	2401.0	2		
2397	8 i.d.	2397.5	1		
2379	8 i.d.				
2372	8 i.d.				
2367	8 i.d.				
2349	8 i.d.				
2345.5	8 i.d.				
2339	6 i.d.				
2327.5	7 i.d.				
2324	7 i.d.				
		2318.4	5		
		2308.7	6n.		
2304	6 i.d.	2303.2	8		
2297	7 i.d.	2298.0	9	2298.4	6
		2290.5	4		
2290	beginning of second wide band				
		2277.5	10	2278.4	9n.
		2269.2	6		
				2258.6	10n.
		2250.4	beginning of second wide band	2251.0	beginning of second wide band

IV. DISCUSSION

The following changes in the absorption spectrum with reduction of pressure may be noticed; they are evident from the plates.

1. As the pressure is reduced from three atmospheres to two, and from two to one, the bands become narrower and fainter, and the less refracted end of the very wide continuous band retreats toward the shorter wave-lengths, this part of the continuous absorption being replaced by narrow bands.

2. At the low pressures—namely $1\frac{1}{2}$, 0.45, 0.13 cm—the above changes are more marked; the narrow bands existing at one or more atmosphere's pressure have entirely disappeared; the wide continuous band has retreated not only from the longer wave-lengths but also from the shorter; and there is very little absorption beween

λ 257 and 230 $\mu\mu$. At the lowest pressure used, a pressure somewhat less than 0.13 cm, the wide continuous band is entirely broken up into narrow bands.

The shortest wave-length photographed was 210 $\mu\mu$; from this wave-length to 230 $\mu\mu$ the absorption decreases with the pressure, but is ill-defined, probably on account of the weakness of the continuous background.

A set of photographs has been taken of the absorption by a column of gas 20 cm in length with the gas at a pressure of 1.35 cm. Since the product

$$(\text{pressure of gas})\times(\text{length of column of gas})=207\times 0.13=20\times 1.35\ ,$$

the number of molecules which the beam meets in traversing a column of gas 207 cm long at a pressure of 0.13 cm is the same as it meets in traversing a column 20 cm long at a pressure of 1.35 cm. Since the numbers of molecules met in the two cases is the same we might expect the absorption to be the same, provided the physical condition of the molecules is the same. It was found that the absorption spectrum obtained from the column of gas 20 cm long at a pressure of 1.35 cm, corresponds very closely with that obtained from the column of gas 207 cm long at a pressure of 0.03 cm, but certain bands in the former are shifted toward the more refracted end of the spectrum; this is obvious from the photograph.

Photographs with this short column at pressures of 1.0 and 0.53 cm show the wide continuous band being gradually broken up into narrow bands. It is intended to extend this part of the work at the earliest opportunity.

Any mathematical relation between the wave-lengths of the bands or their reciprocals is obscure, particularly at the pressures of one or more atmospheres. The reciprocals of the wave-lengths with their differences are shown in Table III.

The differences of the frequencies suggest that the bands are arranged in groups with roughly equal differences between the first bands of successive groups; or we may regard the bands as arranged in series with roughly equal differences between the reciprocals of successive members of a series. Where the members of a series are scattered in Table III, they have been collected at the foot of

TABLE III

Wave-Lengths and Their Reciprocals at Pressure of 2 Atmospheres

λ	$\frac{1}{\lambda} \times 10^7$	Successive Diff'r'nces	Group Differ.
3881.5	2576.3		
		1.9	
3878.7	2578.2		35.7
		33.8	
3828.5	2612.0		
		36.0	36.0
3776.4	2648.0		
		17.8	
3751.2	2665.8		20.7
		2.9	
3747.2	2668.7		
		32.9	32.9
3701.5	2701.6		
		32.5	32.5
3657.5	2734.1		
		2.3	
3654.4	2736.4		
		2.9	
3650.6	2739.3		
		11.4	25.7
3635.4	2750.7		
		5.3	
3628.4	2756.0		
		3.8	
3623.5	2759.8		
		22.6	
3594.0	2782.4		34.2
		11.6	
3579.1	2794.0		
		36.9	36.9
3532.4	2830.9		
		2.4	
3529.5	2833.3		
		5.8	
3522.2	2839.1		
		8.0	
3512.3	2847.1		23.4
		1.8	
3510.1	2848.9		
		2.4	
3507.2	2851.3		
		3.0	
3503.5	2854.3		
		7.7	
3494.0	2862.0		
		3.2	23.6
3490.2	2865.2		
		3.3	
		(9.4)	

λ	$\frac{1}{\lambda} \times 10^7$	Successive Diff'r'nces	Group Diff'r'nces
3486.2	2868.5		
		9.4	
3474.7	2877.9		
		26.4	26.4
3443.2	2904.3		
		6.8	
3435.1	2911.1		
		2.5	
3432.2	2913.6		
		8.6	
3422.1	2922.2		22.2
		0.7	
3421.3	2922.9		
		2.2	
3418.7	2925.1		
		1.4	
3417.1	2926.5		
		8.7	
3406.9	2935.2		
		8.4	
3398.3	2943.6		
		1.1	
3395.9	2944.7		
		1.8	26.0
3393.9	2946.5		
		1.7	
3392.0	2948.2		
		2.3	
3389.3	2950.5		
		2.0	
3387.0	2952.5		
		2.0	
3384.7	2954.5		
		5.8	
3378.0	2960.3		
		1.9	
3375.9	2962.2		25.1
		3.4	
3372.0	2965.6		
		5.4	
3365.9	2971.0		
		6.6	
3358.4	2977.6		

SERIES OF BANDS

$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference
I		II		III	
				2830.9	
		2847.1			23.4
2851.3			21.4	2854.3	
	26.6	2868.5			
2877.9			45.1 $=22.5\times 2$		68.6 $=22.9\times 3$
	26.4				
2904.3					
	22.2	2913.6			
2926.5			21.6	2922.9	
	26.0	2935.2			23.6
2952.5			19.3	2946.5	
	25.1	2954.5			24.5
2977.6				2971.0	

AT PRESSURE OF $1\frac{1}{2}$ CM

λ	$\frac{1}{\lambda}\times 10^7$	Successive Diff'r'nces	Group Diff'r'nces	λ	$\frac{1}{\lambda}\times 10^7$	Successive Diff'r'nces	Group Diff'r'nces
3226.2	3099.6			2456	4071.5		
		14.3				28.5	28.5
3211.4	3113.9		18.0	2439	4100		
		3.7				40	40
3207.6	3117.6			2415.5	4140		
		4.1				25	
3203.4	3121.7			2401	4165		32
		5.0				7	
3198.3	3126.7			2397	4172		
		2.8	20.0			31.5	31.5
3195.4	3129.5			2379	4203.5		
		5.0				12.5	
3190.3	3134.5			2372	4216		23.5
		3.1				11	
3187.1	3137.6			2367	4225		
		6.5				32	32
3180.6	3144.1			2349	4257		
		9.0	20.8			6.5	
3171.5	3153.1			2345.5	4263.5		18
		5.3				11.5	
3166.2	3158.4			2339	4275		
		8.7				21.5	
3157.5	3167.1			2327.5	4296.5		28
		4.8	19.6			6.5	
3152.7	3171.9			2324	4303		
		6.1				37	37
3146.6	3178.0			2304	4340		
						14	
				2297	4354		

SERIES OF BANDS

$\frac{1}{\lambda}\times10^7$	Difference	$\frac{1}{\lambda}\times10^7$	Difference	$\frac{1}{\lambda}\times10^7$	Difference
I		II		III	
3099.6		3113.9		3117.6	
	22.1		20.6		20.0
3121.7		3134.5		3137.6	
	22.4		18.6		20.8
3144.1		3153.1		3158.4	
	23.0		18.8		19.6
3167.1		3171.9		3178.0	

AT PRESSURE OF 0.13 CM

λ	$\frac{1}{\lambda}\times10^7$	Successive Differences	Group Differences
3180.7	3144.0		
		28.7	
3151.9	3172.7		
		2.1	
3149.8	3174.8		
		2.0	
3147.8	3176.8		
		2.5	
3145.3	3179.3		
		2.4	
3143.1	3181.7		
		5.3	
3137.7	3187.0		20.0
		6.9	
3131.0	3193.9		
		2.3	
3128.7	3196.2		
		3.1	
3125.7	3199.3		
		5.5	
3120.3	3204.8		
		9.3	20.5
3111.3	3214.1		
		5.7	
3105.8	3219.8		
		4.6	
3101.4	3224.4		20.6
		16.0	
3086.0	3240.4		
		22.3	22.3
3064.9	3262.7		
		22.6	22.6
3043.9	3285.3		
		23.1	23.1
3022.6	3308.4		
		20.9	20.9

λ	$\frac{1}{\lambda}\times10^7$	Successive Differences	Group Differences
3003.6	3329.6		
		17.3	17.3
2988	3343.6		
2701.5	3701.6		
		11.0	
2693.5	3712.6		
		12.1	
2684.8	3724.7		23.3
		11.2	
2676.7	3735.9		
		11.1	
2669.5	3746.0		21.3
		13.2	
2660.1	3759.2		
		7.4	
2654.9	3766.6		
		2.3	
2653.3	3768.9		24.4
		8.8	
2647.1	3777.7		
		5.9	
2643.0	3783.6		
		7.2	
2638.0	3790.8		
		7.1	22.3
2633.0	3797.9		
		8.0	
2627.5	3805.9		

AT PRESSURE OF 0.13 CM (CONTINUED)

λ	$\frac{1}{\lambda}\times 10^7$	Successive Differences	Group Differences
		6.4	
2623.1	3812.3		
		3.2	
2620.9	3815.5		
		5.8	20.1
2616.9	3821.3		
		2.2	
2615.4	3823.5		
		2.5	
2613.7	3826.0		
		3.4	
2611.4	3829.4		
		21.5	21.5
2596.8	3850.9		
		8.0	
2591.4	3858.9		
		9.3	21.0
2585.2	3868.2		
		3.7	
2582.7	3871.9		
2512.2	3980.6		
		26.0	26.0
2495.9	4006.6		
		28.8	28.8
2478.1	4035.4		
		10.6	
2471.6	4046.0		22.5
		11.9	
2464.3	4057.9		
		16.9	26.6
2454.1	4074.8		
		9.7	
2448.3	4084.5		
		25.5	25.5
2433.1	4110.0		
		54.9	2×27.5
2401.0	4164.9		
		6.1	
2397.5	4171.0		
2318.4	4313.3		
		18.1	
2308.7	4331.4		28.5
		10.4	
2303.2	4341.8		
		9.8	
2298.0	4351.6		
		25.3	25.3
2290.5	4376.9		
		13.9	
2277.5	4390.8		29.9
		16.0	
2269.2	4406.8		

SERIES OF BANDS

$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference
I		II		III	
3701.6					
	23.1	3712.6			
3724.7			23.3		
	21.3	3735.9			
3746.0			23.3		
	22.9	3759.2			
3768.9			24.4	3777.7	
	21.9	3783.6			20.2
3790.8			22.3	3797.9	
	21.5	3805.9			23.4
3812.3			20.1	3821.3	
		3826.0			
			24.9		
		3850.9			
			21.0		
		3871.9			

LENGTH OF COLUMN OF GAS = 20 CM
AT PRESSURE OF 1.35 CM

λ	$\frac{1}{\lambda} \times 10^7$	Successive Differences	Group Differences
3178.6	3146.4		
		28.2	28.2
3150.0	3174.6		
		21.0	21.0
3129.3	3195.6		
		4.8	
3124.6	3200.4		
		20.5	20.5
3104.7	3220.9		
		12.0	
3093.2	3232.9		
		3.7	21.4
3089.7	3236.6		
		3.6	
3086.2	3240.2		
		2.1	
3084.2	3242.3		
		1.9	22.0
3082.4	3244.2		
		20.1	
3063.4	3264.3		
		22.4	22.4
3042.6	3286.7		
		22.7	22.7
3021.7	3309.4		
		22.4	22.4
3001.4	3331.8		
		22.2	22.2
2981.5	3354.0		
		22.1	22.1
2962.0	3376.1		
		21.8	21.8
2943.0	3397.9		

λ	$\frac{1}{\lambda} \times 10^7$	Successive Differences	Group Differences
2692.3	3714.3		
		11.9	22.2
2683.7	3726.2		
		10.3	
2676.3	3736.5		
		10.8	23.7
2668.6	3747.3		
		12.9	
2659.4	3760.2		
		8.8	
2653.2	3769.0		
		9.4	23.5
2646.6	3778.4		
		5.3	
2642.9	3783.7		
		8.1	
2637.3	3791.8		
		6.6	22.8
2632.7	3798.4		
		8.1	
2627.1	3806.5		
		8.5	19.3
2621.2	3815.0		
		10.8	
2613.8	3825.8		
		26.0	26.0
2596.2	3851.8		
		8.0	18.9
2590.8	3859.8		
		10.9	
2583.5	3870.7		
2496.2	4006.1		
		30.1	
2477.6	4036.2		
		10.1	
2471.4	4046.3		
		27.9	
2454.5	4074.2		
		10.9	
2447.9	4085.1		
2298.4	4350.9		
		38.1	
2278.4	4389.0		
		38.5	
2258.6	4427.5		

SERIES OF BANDS

$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference
3714.3					
	22.2	3726.2			
3736.5			21.1		
	23.7	3747.3			
3760.2			21.7		
	23.5	3769.0			
3783.7			22.8	3778.4	
	22.8	3791.8			20.0
3806.5			23.2	3798.4	
		3815.0			27.4
				3825.8	
					26.0
				3851.8	

the subdivisions of that table. These differences change gradually with the wave-length; they decrease from the longer to the shorter wave-lengths until the wide band is reached, then increase on the other side of it. The direction of this change corresponds with the change in absorption as the pressure is reduced; the bands decrease in intensity and eventually disappear first in the longer wave-lengths on the less refracted side of the wide band, and at the same time in the shorter wave-lengths on the more refracted side.

Region	Mean Difference in Frequency
380 to 350 $\mu\mu$	34
350 to 330 $\mu\mu$	25
330 to 313 $\mu\mu$	20
318 to 298 $\mu\mu$	21
272 to 258 $\mu\mu$	22
250 to 230 $\mu\mu$	30

Photographs taken with the column of gas 20 cm long show a rather more regular structure of bands; also some groups or series.

These groups of bands or series, combined with the breaking up of the wide continuous band into a considerable number of narrow bands as the pressure is reduced, suggest the possibility that all these bands may eventually be found to consist of very narrow bands or lines.

V. CONCLUSION

Although the series are at least in some cases incomplete and the differences in the wave-numbers are not equal, yet the near approach of these differences to equality with one another cannot be ignored. Thus this spectrum appears to consist of series of bands which follow approximately a law of equal differences. With the gas under conditions of pressure and temperature other than those tried, it may be found that its spectrum consists of quite definite series which follow closely a law of equal differences between the wave-numbers.

II. THE BAND EMISSION SPECTRUM OF SULPHUR DIOXIDE

I. APPARATUS AND METHOD

The usual conditions necessary to maintain the gas as a compound while under the electrical discharge were obtained as follows: The feeble electrical excitation was obtained from the secondary of a ten-inch induction coil, the primary of which was supplied with the current from three storage cells; the terminals of the secondary were placed too far apart for a spark to pass between them, and the vibrator was adjusted loosely. The spectrum tube had outside electrodes of lead foil with a layer of mica between them and the glass walls. As a further aid in preventing the decomposition of the gas, electrolytically prepared oxygen was mixed with the sulphur dioxide in the spectrum tube.

The sulphur dioxide was obtained from liquid sulphur dioxide which had been redistilled. The gas was dried by passing it through a bulb closely packed with phosphorus pentoxide; it was then admitted to the apparatus through a barometer column. Interposed between the barometer column and the spectrum tube were two U-tubes, one containing gold foil to absorb mercury vapor, and the other packed with phosphorus pentoxide to insure more perfect dryness of the gas. Similar tubes were interposed between the other end of the spectrum tube and the McLeod gauge and vacuum pump. All connections of the apparatus from the barometer column to the far side of the pump were either blown glass joints or mercury seal joints.

The spectrum tube was cleaned by soaking it in chromic acid

for ten or twelve hours, then washing it with distilled water, then with nitric acid, and again with distilled water; it was then dried by keeping it at a temperature of from 110° to 120° C. for eight or ten hours, meanwhile drawing a current of dry air through it. No bands from carbon compounds nor any of the strong hydrogen lines were ever seen or found on a photographic plate. The tube was exhausted, sparked, filled with oxygen, re-exhausted, and the process repeated until no air lines appeared.

The oxygen was prepared electrolytically from a 20 per cent. solution of crystallized phosphoric acid and dried by passing it through two bulbs loosely packed with phosphorus pentoxide and then through a U-tube closely packed with the same and plugs of glass wool. The line spectrum of oxygen was photographed in the region between λ 327 and 432 $\mu\mu$. It is well known that oxygen has no bands in this region.

As a standard spectrum that of the iron spark was used with the wave-lengths published by Kayser in his *Handbuch der Spectroscopie*, Vol. I.

The spectral apparatus was a Rowland concave grating mounted on the Rowland plan; it has a radius of 180 cm (5 ft. 11 in.), 15,028 lines to the inch, and a ruled surface 52 mm ($2\frac{7}{16}$ in.) wide. The wave-lengths were determined in the usual way by measurements made by means of the dividing engine mentioned above; the reduction factor was approximately 9.3 tenth-meters to 1 mm.

II. RESULTS

The chief difficulty in obtaining the spectrum of the compound lay in the extreme faintness of the light and the long exposures necessary. With the light from the capillary used "end-on" and a slit-width of about 0.05 mm, a continuous exposure of 45 hours gave only weak bands in the ultra-violet and very weak bands in the violet; the lines of the bands were too coarse for measurement. The wave-lengths of the heads of the bands obtained from this photograph are given in Table IV. A continuous exposure of 69 hours with a slit-width of 0.035 mm approximately gave bands too faint for measurement. A continuous exposure of 91 hours with a slit-width of 0.018 mm approximately was spoiled by ham-

mering in another room in the building. For the spectrum for which measurements are given the pressure of sulphur dioxide was 0.27 cm, and the pressure of oxygen 0.28 cm making a total pressure of 0.55 cm at the beginning of the exposure. During exposure, oxygen and sulphur dioxide were added to try to keep the condition of the tube constant; the total pressure at the end of the exposure was 0.45 cm. Hitherto no attempt has been made

TABLE IV

BAND EMISSION SPECTRUM OF SULPHUR DIOXIDE

WAVE-LENGTHS OF THE HEADS OF THE BANDS AND THEIR RECIPROCALS

	λ	Intensity and Character	$\frac{1}{\lambda}\times 10^7$	Successive Differences
1	3271.4	4	3056.8	101.5
2	3383.7	5	2955.3	38.2
3	3428.0	4	2917.1	61.9
4	3502.3	5	2855.2	37.3
5	3548.7	5	2817.9	61.6
6	3628.0	4	2756.3	35.9
7	3675.9	5	2720.4	36.9
8	3726.5	2	2683.5	25.0
9	3761.5	f	2658.5	34.7
10	3811.3	5	2623.8	35.0
11	3862.7	2	2588.8	60.1
12	3954.6	5 h.	2528.7	33.5
13	4007.6	4 h.	2495.2	20.3
14	4040.6	3 v.i.d.	2474.9	40.2
15	4107.3	2 i.d.	2434.7	22.4
16	4145.5	2	2412.3	4.6
17	4153.4	2	2407.7	5.6
18	4163.0	3 h.	2402.1	

TABLE V

SERIES OF BANDS

$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference	$\frac{1}{\lambda}\times 10^7$	Difference
I		II		III	
1) 3056.8					
	101.5	3) 2917.1			
2) 2955.3			99.2		
	100.1	5) 2817.9			
4) 2855.2			97.5		
	98.9	7) 2720.4			
6) 2756.3			96.6	8) 2683.5	
	97.8	10) 2623.8			94.7
9) 2658.5			95.1	11) 2588.8	
		12) 2528.7			93.6
			94.0	13) 2495.2	
		15) 2434.7			93.1
				18) 2402.1	

to photograph this spectrum in regions of greater wave-length where longer exposures would be necessary.

The spectrum thus obtained consists of bands with distinct heads turned toward the ultra-violet, and is thus characteristically different from the "band" or compound line spectrum of elementary sulphur obtained by Eder and Valenta, and published in their paper, "Die Spectren des Schwefels," 1898.

The reciprocals of the wave-lengths (Table IV) show that the bands can be arranged in three series with decreasing difference of wave-numbers (Table V). The series will be seen to follow roughly Deslandres' law. These series are doubtless incomplete, as the range photographed covers only 105 $\mu\mu$.

My investigation of the spectrum of sulphur dioxide was begun originally at the suggestion of Professor A. Stanley Mackenzie with the purpose of comparing it with that of sulphur as determined by Runge and Paschen and by Eder and Valenta. Owing to various causes, this plan was not carried into effect, and the research as described in the preceding pages was proposed by Professor J. S. Ames, to whom I desire to express my indebtedness and my gratitude for his kindness in directing my work and for his invaluable suggestions in the carrying out of this investigation. I wish at the same time to express my thanks to Dr. H. W. Springsteen, asso-

ciate in physics, for the generosity with which he has provided me with the laboratory apparatus needed for this piece of work; also to Dr. W. B. Huff, professor of physics, and to Dr. E. P. Kohler, professor of chemistry, for frequent help and encouragement, particularly during the early part of my work.

BRYN MAWR COLLEGE,
March 31, 1906.

Minor Contributions and Notes

REMARKS ON MR. C. L. POOR'S PAPERS ON THE FIGURE OF THE SUN

In the second and fifth numbers of the last volume of this *Journal*[1] Mr. C. L. Poor has published some investigations as to the figure of the Sun, in which he believes that he has proved the existence of periodic changes. I am led to discuss briefly his research here, inasmuch as he has included in his considerations my memoir on the Göttingen heliometer measurements of the Sun's diameter, and has sought to show that it contains certain oversights. After being busied for years with this subject, I am for my part by no means convinced by the presentation of Mr. Poor; but I here wish to show by a few examples that his investigations are not quite to the point. I shall give elsewhere a full discussion of them.

The results from the earlier photographic plates surely did not possess the precision necessary for proving such oscillations of the ratio between the polar and equatorial diameter; for, according to our heliometer measurements, it is quite beyond the possibility that these variations, if present at all, can exceed 0".1 by an appreciable amount; but our measurements in the year 1894 furnish for the more recent photographs just the proof that the oscillations adduced by Mr. Poor are not present, as is shown by the following summary for P.—E.

Photographic Measures	Heliometer Measures		
Poor	Schur	Ambronn	Mean Schur and Ambronn
1894 July 10 −0".72±0".24	July 6 +0".15	July 7 −0".25	−0".05
July 17 +0.36±0.23	July 24 −0.25	July 25 −0.04	−0.14

I would remark as to the errors found by Mr. Poor in my memoir that only the one adduced for the year 1898 should be actually regarded as such. It should actually there read +0".11 instead of −0".11, and the slip is due to the fact that in Schur's summaries, not all of which were subsequently computed by me (since they had been made out with the greatest of care), an error was evidently left in the transcription of a number. The three other errors, however, are not present in the table on

[1] **22**, 103–114, 305–317, 1905.

page 44 of my paper. The number for 1891 is there given perfectly correctly, but in the copy of the special summary of the deviations on page 108 there is a typographical error. For September 10/11 we should read under P.—E. $-0\rlap{.}''64$ instead of $-0\rlap{.}''04$, as might at once have been seen from the original data on page 74. The figure for the year 1896 is entirely correct in my table on page 44, on which alone the discussion was based; the figure for Schur's observations in 1900 includes, however, the wholly isolated measure in 1901, and is then entirely correct, which fact Mr. Poor seems to have overlooked.

There therefore remains, as affecting the whole consideration, solely the error for 1894, and it is easy to see that this is without any signification as to the result, from the circumstance that this high positive value owes its origin to an entirely accidental accumulation of observations in May and June, and the single observation of December 7, designated by Schur himself as very poor. (See page 84 of my paper.) It is not at all confirmed by the inclusive observations of Schur and myself in May and June 1898.

Although the derivation of variations of the solar diameter in polar and equatorial directions is thereby made very improbable, I must nevertheless here further state that later Mr. Poor still includes in his discussion the observations for the years 1890 and 1891. These should in this case certainly be excluded, because we can *not* exclude from these measurements any physiological error which might be present affecting the two directions unequally. If we take this into account, not only are the conclusions based on the curves upset, but also the tables on pages 310 and 313 take an entirely different form. The mean errors of a year's average for the value of P.—E. come out as about $+0\rlap{.}''07$ and $+0\rlap{.}''06$ for Schur and Ambronn, respectively, if we assume in round numbers sixteen observations in the year. These errors are, however, such that almost all the year's averages for P.—E. fall between these limits during the years 1892–1902, which *alone* ought to be considered. Hence in my view there is no occasion at all, on the basis of our heliometer measurements, to assume such periodic variations as Mr. Poor believes he has found. It would have been very interesting to me to have been able to establish such a periodicity from my discussion of the Göttingen heliometer observations, but the most thorough investigation of the large amount of data collected by us has convinced me that this furnishes no justification for such a periodicity.

L. AMBRONN.

GÖTTINGEN,
February 25, 1906.

NOTE ON THE ULTRA-VIOLET RADIATION OF SUN-SPOTS AND FACULÆ

In connection with the investigations of Messrs. Hale, Adams, and Abbot on the radiation of sun-spots[1] we beg to communicate a few observations on the ultra-violet radiation of sun-spots and faculæ. These are based on the solar plates taken with light of wave-length 320 $\mu\mu$, upon which we report fully elsewhere in this number. We were struck at the beginning by the fact that the umbræ of the larger spots on these plates exhibit strong contrast to the surroundings. Measurements were made in the following manner. A setting was made under a Hartmann photometer on the opacity of the spot upon a solar image obtained with the full aperture of the instrument, and then upon the image taken with a diaphragm $\frac{1}{4}$, which was situated on the same plate, an undisturbed place was sought out which exhibited the same opacity, and the distance of this point from the limb was determined. Since the falling off in the brightness of the Sun's disk from the center toward the edge was known from the previous investigation, this gave directly the brightness of the spot, which could then be referred to the normal brightness of the Sun at an equal distance from the limb as unity. It was only in case of the exceedingly dark spot of November 16 that no suitable opacity for comparison could be found on the plate, and a small extrapolation had to be made from the opacity-curve.

The measurements were rendered for the most part rather difficult by the fact that the nucleus of the sun-spot did not entirely fill the spot in the photometer.

Date	Distance from Center	Umbra	Penumbra	Remarks
1905				
January 17 . . .	0.72	0.21	0.52	Single spot on west limb
	0.27	0.14	0.64	Great spot group
	0.78	0.40	. . . .	Single spot on east limb
January 18 . . .	0.83	0.35	. . . .	Single spot on west limb
	0.42	0.11	0.47	Great spot group
	0.65	0.47	. . . .	Single spot on east limb
June 28.	0.53	0.13	0.49	Great spot group
	0.69	0.11	0.69	Single round spot
October 16 . . .	0.73	0.032	0.52	Great group
November 9 . .	0.83	0.30	. . . .	Single spot
	0.43	0.019	0.60	Single round spot
December 25. .	0.67	0.12	0.63	Three neighboring spots on west limb
	0.75	0.12	. . . .	
	0.88	0.55	. . .	

[1] *Astrophysical Journal*, **23**, 43, 1906.

The preceding short table gives, in addition to the date, the distance of the spot from the center of the disk in decimals of the radius, the brightness of umbra and penumbra in comparison with the brightness of an undisturbed place at equal distance from the center, and finally a few general remarks to designate the spot.

Faculæ may be followed in many instances on our plates in long curves to the exterior half of the Sun's radius, but in no place does their brightness exceed by more than 20 or 30 per cent. that of the undisturbed neighborhood.

K. SCHWARZSCHILD AND W. VILLIGER.

A THEORY FOR THE DISTRIBUTION OF SPECTRAL LINES IN SERIES

A comparatively recent attempt has been made by Professor F. von Lindemann[1] to account for the distribution of spectral lines in series. His method is to investigate the possible waves which a hypothetical atom of matter will send out into the surrounding luminiferous ether. He assumes that the atom in every case consists of elastic isotropic matter which is the same in kind for all substances, but is different in shape, size, density, and elasticity. The mathematical theory of the various modes of vibration which such a body can assume has been worked out before, but the application of the same to bodies of definite shape has been difficult because it involves the discovery of mathematical functions for each shape. The periodicity of each kind of vibration which the body sets up in the ether always occurs as a root of a certain transcendental equation involving those functions. Such an equation has an infinite number of roots, each real one corresponding to a definite spectral line. Every equation thus gives a series of lines. Each body has a number of such equations and therefore a number of such series.

Lindemann has investigated the various cases which admit of mathematical treatment, namely, where the atom is spherical, ellipsoidal, or ring-shaped. Owing to the extraordinary intricacy of the equations, no detailed calculations have yet been made from them. The solutions, for the most part, have been carried only far enough to indicate what the general type of distribution of the lines is for each case.

[1] *Sitz. Math. phys. Klasse d. Kgl. Bay. Akad.*, **31**, 441, 1901; *Ibid.*, **33**, 27, 1903; (Translation of Popular Lecture) *Monist*, January 1906.

In the case of a spherical atom he finds the distribution obeys a law which is simpler than any so far discovered for the elementary substances.

For an atom which has the shape of an elongated ellipsoid of revolution (a prolate spheriod) he finds that the distribution will depend upon three numbers, and hence may be arranged in groups according to three principles. These numbers occur as the roots of certain transcendental equations and are determined by the axes, density, and elasticity of the ellipsoid. The spectra of the alkali metals (lithium, potassium, cæsium, and rubidium) show this type of distribution of lines, so the atoms of these metals may be considered as having the shape of a prolate spheroid.

In the case of an oblate spheroid the spectral lines are found to be arranged according to a different law. The arrangement here resembles that of the lines in the spectra of gold, silver, and copper. The hydrogen spectrum is also of the same type.

In the more general case, where the atom is supposed to have the shape of an ellipsoid with three unequal axes, Lindemann finds that the lines do not fall into series and groups as in the other cases, but are distributed over the whole spectrum. Only when the ellipsoid approximates to a spheroid do the lines fall into series. When the prolate spheroid is approximately obtained, the distribution resembles that of the alkaline earths (barium, strontium, calcium, and magnesium); when the oblate spheroid is approached, the distribution is like that of zinc, cadmium, and mercury.

For a ring-shaped body the distribution of lines is found to resemble that of the oxygen, helium, sulphur, and selenium spectra.

A striking consequence of the foregoing theory is that which results from a change in shape of the spherical atom. The sphere can be thought of as gradually deformed by pressure until it assumes an ellipsoidal shape. By this change the theory shows that each spectral line will give rise to eight new ones. It is easy to see from this how the theory may be made to account for the Zeeman effect.

So far as comparisons have been made between this theory and the established facts, only a few points of agreement have been found. Not until more detailed calculations are made will it be possible to say how closely the theory can be made to account in detail for the distribution of lines in line-spectra.

T. S. Elston.

The Johns Hopkins University.

THE PRESENT CONDITION OF ROWLAND'S RULING MACHINES[1]

As is well known, Professor Rowland designed and had constructed under his direction three machines for the purpose of ruling diffraction gratings. The mechanism of them all was more or less identical, and that of the last is described in full, with drawings, in Rowland's *Physical Papers*, p. 689.

The screws of all three machines have twenty threads to the inch, but owing to differences in the number of teeth in the divided heads, rule gratings with different spaces, viz., 14,438, 15,020, and 20,000 lines to the inch.

Nothing is known of the inception of the idea in Rowland's mind of making these machines; but the first one was constructed in the autumn of 1881. This is the one which rules 14,438 lines to the inch. The next to be made was the one which rules 20,000 lines; and, last of all, the one which rules 15,020 lines. All these machines had been made by the same workmen; the castings were made in Baltimore; the toothed wheels, the screws, and the brass parts were all ground and worked by Theodore Schneider, the instrument-maker of this laboratory.

The first machine was too small to rule large gratings; and, further, all the gratings ruled, with few exceptions, had periodic errors, due, in part, to the fact that the toothed wheel was not solid, but had spokes. Consequently, the second machine was made with a longer screw, a solid toothed wheel, and numerous other improvements. This machine soon proved itself unsatisfactory. In fact, out of all the gratings ruled on it, only one was of the best quality. Numerous attempts were made by Schneider to improve the machine, but Professor Rowland determined to construct an entirely new one. In the meanwhile, Schneider had accidentally dropped a heavy oil-can on the screw of the smaller machine; and its usefulness was much diminished. Finally the third machine, as described above, was completed, and with it all the best gratings have been ruled. Even with it, however, the percentage of good gratings to poor ones was always small, and seemed definitely to be becoming smaller.

Schneider died in the early spring of 1901, and his place as instrument-maker of the laboratory was taken by Charles Childs. Schneider's death was followed almost immediately by that of Professor Rowland, on April 16, 1901. The machines thus came under my care; and my first duty was to have a thorough examination made of all three. The results will be given below. Soon afterwards, Mr. L. E. Jewell, who for many years had tested most of the gratings ruled before they were distributed, returned

[1] From *Johns Hopkins University Circular* No. 186; N. S., 1906, No. 4, April.

to the university; and he was entrusted with the duty of testing all the parts of the machines in detail. Since then he has been immediately in charge of the machines, and all the alterations and improvements have been carried out under his direction.

The result of the examination of the machines may be given as follows:

14,438 machine. Screw injured; divided head of faulty construction.

20,000 machines. Screw imperfect; divided head placed eccentrically on screw; thrust pin, against which screw presses, not in line with screw; the mechanism holding the diamond, too loosely jointed and having the line joining pivots out of line; the journals holding the screw too loose and out of line.

15,020 machine. Screw good; divided head correctly placed; thrust pin out of line; mechanism holding the diamond very faulty; the wooden plugs in the nut loose and in some cases decayed.

None of the machines was provided with oil-cups of any kind; the metal surfaces in contact, and where there was relative motion, were in some cases improperly chosen, and in all cases the friction was altogether too great. There were also numerous defects in the shafting, the shapes of the cams, etc., all of which were easily remedied.

It was a most serious question to know what to do in order to place the machines in working order. It was obvious that the defects in them were not in design, but in execution. During the last years of Rowland's life he had been so occupied by other investigations that he had left the entire control of the machines in the hands of others; in fact, it is doubtful if Rowland even looked at the machines for a year before he died.

It was evident that the smallest machine was useless so far as ruling diffraction gratings was concerned; and it was removed from its position in the vault and taken to one of the upper rooms. At the time of the exhibition in St. Louis in 1904, this machine was placed on view among the other pieces of apparatus of historic interest from this laboratory. Unfortunately, it was carelessly packed, and the toothed wheel was injured in transit. These bent teeth have been replaced, but no further attempt has been made to put the machine in condition.

The 20,000 machine was evidently beyond hope, except in so far as the frame could be used. All the brass parts have since been corrected or replaced; the divided head has been properly set, etc.; but, most important of all, a new screw and a new nut have been made. A few words will be said in regard to these later. This reconstructed machine has been tested and found to be nearly free from errors. Work on it is not yet completed, but it is expected that gratings will be ruled within a fortnight.

One of the most important modifications has been to introduce an anti-friction alloy on the two platforms, and to attach counterbalancing weights to the platform which carries the grating, so as to diminish pressure and friction on the ways when heavy gratings are placed on the platform. Numerous devices of less importance have also been introduced.

The 15,020 machine was in the best condition of the three, although that was far from being satisfactory. It was determined to make as many simple corrections as were possible, to exercise better care in the choice of ruling points, to maintain a more constant temperature, and not to attempt to rule any more large gratings than were absolutely necessary. Unfortunately, this last determination was not adhered to at first, and disastrous consequences resulted; more of the wooden plugs in the nut became loosened. These were tightened temporarily, and many gratings have been ruled. A much larger percentage of these are good than was ever the case in previous years; and the best are so far better than the highest grade that was formerly produced that an entirely new quality had to be described and listed. As soon as the new 20,000 machine is working properly, this machine will be taken apart and reshaped. The most important improvement will be a new nut.

A few words should be said in regard to the new screw and nut of the 20,000 machine. A full description will be published as soon as facts in regard to its actual use are at hand. The screw was cut on a Reed lathe, and was ground by a special nut, made of a fusible metal and *cast on the screw* itself. Similarly, the ruling nut, like the grinding one, was cast on the screw. The advantages over the wooden plug nut as used on the old machines are obvious; chief among them are the saving of time in grinding and the diminution of error owing to differential expansion, due to temperature changes between screw and nut.

The new screw and nut were designed by Mr. Jewell and were made by Childs; and both for this and for the other improvements in the machines all those interested in the science of spectroscopy owe a debt of gratitude to Mr. Jewell's great ingenuity and to Child's mechanical skill.

J. S. Ames.

PROFESSOR ERNST ABBE

Rochester, N. Y., March 22, 1906.

A little more than a year ago there died in Jena, that world-famous town, Professor Ernst Abbe, who has had no small share in making Jena so well known to the entire civilized world.

At the time of his death, papers and magazines contained full accounts of the life and work of this truly remarkable man, reciting in detail his numerous contributions to science and his successful experiment in organizing an industrial enterprise upon distinctively new lines.

Since that time the feeling that here was a man whose work has been for the good of mankind and whose memory should be fittingly honored, gathered strength until there was appointed a committee to take charge of soliciting funds for the purpose of erecting in his native town, between the Volkshaus erected by him and the Zeiss Works, a statue as a memorial.

The names of a number of American scientists and business men who had had dealings with the Zeiss Works were included in the committee named. We in America seem very far off from the little German town where the statue to Abbe is to be placed; and one might think it of little account whether we help to erect the statue or not. But this is a unique occasion, as Abbe was a unique man, and most of us who know anything at all about him will consider it a privilege to be able to contribute, be it ever so small a sum, to the statue that is to perpetuate his form to posterity.

The undersigned have for many years had business relations with Professor Abbe through the Carl Zeiss Works. They have, therefore, a strong desire, a desire tinged by personal acquaintance, to see America well represented in this memorial. They believe that many will be glad to avail themselves of the opportunity of giving something to show their appreciation of the great work done by Abbe and in order that such opportunity may not be wanting they have arranged, with the consent of the other members, to act as secretary and treasurer of the American Committee to solicit funds for this purpose.

Under date of February 25th the American Microscopical Society issued a circular letter appealing to their members to aid in this movement. We would state that we have no desire to interfere in any

way with the collections that might be made by the Society, in fact we would urge, since our purpose is only to help increase the fund, that all contributions of members or others interested in the Society be sent direct to them, since it is eminently fitting that such an organization should make as good a showing as possible.

We urgently request all others who are interested to send contributions to us, be they large or small, and ask all to assist by giving as much publicity as possible to the scheme, and by endeavoring to arouse interest and enthusiasm in the project.

We shall make personal acknowledgment immediately upon receipt of contributions and shall publish list of contributors as soon as the total amount is forwarded to Germany.

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